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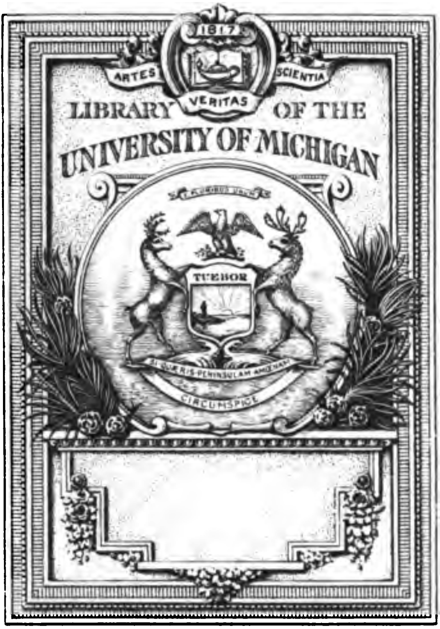

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PRACTICAL
FIELD GEOLOGY

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BY

J. H. FARRELL, E. M.

MINING GEOLOGIST

INCLUDING

A GUIDE TO THE SIGHT RECOGNITION OF ONE
HUNDRED AND TWENTY COMMON
OR IMPORTANT MINERALS

BY

ALFRED J. MOSES, E. M., Ph. D.

PROFESSOR OF MINERALOGY, COLUMBIA UNIVERSITY

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PREFACE

"When 'Omer smote 'is bloomin lyre,
He'd 'eard men sing by land an' sea;
An' what he thought 'e might require,
'E went an' took—the same as me."
KIPLING.

Within the last few years the importance of applied, or "practical" geology has received very wide recognition. But while it is freely admitted that the results obtained by specialists in this field are often of inestimable value in the conduct of mining operations, there is no very general understanding of the methods employed in their work.

Geological maps are just as necessary as ordinary maps of mine workings, and are not much harder to make when one knows how to go about it. It is the lack of this knowledge which is a serious handicap to many mining men who are naturally keen and intelligent observers, but who fail to record and correlate their observations. They often carry an immense amount of geological data in their minds and make use of it when looking over their mine maps; but such mental pictures lack the graphic quality found only in good geologic maps and sections, which usually meet with instant approval on the part of practical men.

Geological literature usually deals with results rather than with the methods of obtaining them, and the terms employed are often of a highly technical nature, so that the text is more or less unintelligible to one who has not had training in the subject.

With these ideas in mind I have tried to outline briefly and plainly the means employed in geological mapping, and in the interpretation of geological data. I have also attempted to indicate some lines along which the application of geological theory may be made. The work may be characterized as elemen-

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tary, and no doubt it is from the viewpoint of the trained geologist; but I hope that it will be of some value to those who have had no specialized geological training, or to whom economic work is a new field.

The methods of topographic mapping are modified from those of the United States Geological Survey and are adapted to use on the smaller areas comprised by mining properties of average size. I have not attempted to give thorough theoretical discussions, nor have I described all the methods of surface mapping which might find application in such work. My idea is rather to offer a general scheme of procedure which may be modified to suit different cases.

The chapters on geologic mapping are the result of several years of experience in the Western mining districts, and are based on notes made when such work was new to me; so that it is to be hoped that they will cover those points which are most important for the beginner to understand.

For a part of the material presented I wish to express my thanks to the authors who have allowed me unrestricted use of their work. Professor A. J. Moses' mineralogical tables and descriptions will be appreciated by all who have occasion to refer to them. They are especially valuable for field use in economic work since they include all the most important ore and gangue minerals, and the rock-forming minerals. Professor Joseph W. Roe's paper, "The Application of Descriptive Geometry to Mining Problems," is one of the best and most logical contributions to the subject of geological measurements that has appeared for some time. Mr. S. K. Bradford's paper, "A Portable Assay Outfit for Field Work," treats the subject in a very practical manner and offers a solution to a problem that has vexed many prospectors and exploring geologists.

I am indebted to Professor J. F. Kemp of Columbia University for permission to use some of the material in his "Handbook of Rocks," and also for information obtained in some of his courses. I am also indebted to Dr. Charles P. Berkey of Columbia for suggestions and ideas offered in his course in petrography, and for a general opinion upon this book prior to publication. Mr. C. O. Lindberg, Mr. Alvin Carpenter, and Mr. Rolfe McCollom, mining engineers of Los Angeles, Cal., also gave valuable assistance in reading the manuscript and suggesting changes and additions.

J. H. FARRELL

LOS ANGELES, CALIFORNIA.
July 1, 1912.

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PRACTICAL FIELD GEOLOGY

CHAPTER I

PLANE TABLE AND STADIA SURVEYING

In the course of my work in the field I have found that relatively few people realize the advantages of the use of the plane table in mapping which does not require the greatest degree of accuracy. In fact the general impression is that such methods went out of date along with the compass. In connection with stadia measurements the plane table is of very great value for topographic mapping, and with a good telescopic alidade secondary triangulation of considerable accuracy may be carried out upon the field map. These methods of surveying have been developed largely by the topographers of the Government surveys, and adaptions of them have been made to the work of mapping smaller areas in connection with mine examination work. The following chapters outline in detail the way in which such maps are made; but first it may be well to describe the instruments used in this kind of work.

Plane Table Outfit.—A plane table outfit consists of board, movement and tripod, the alidade, with striding level, and a compass.

The board, about 24 in. × 30 in. in size, is provided with screws for holding the map sheet, and has a socket into which screws a piece from the "movement."

The "movement," Fig. 1,[1] is a sort of socket-joint which makes the tripod head; it is controlled by means of two wing nuts, one of which may be clamped when the board is level; the board is then turned until it is properly oriented, when it is clamped rigidly by the second wing nut. In place of this device regular leveling screws may be used similar to those on a transit; with them it is somewhat easier to set up the table quickly.

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[1] Cut furnished by Bausch & Lomb Optical Company.

Use of the Plane Table.—A plane table is essentially a drawing board of convenient size which may be mounted on a tripod, adjusted until its surface lies in a true horizontal plane, and then revolved about its center to the desired position or orientation. Upon this board is carried a sheet of drawing paper on which are plotted the points of which the locations are known; these are usually the triangulation points, the method of locating them will be given in the next chapter.

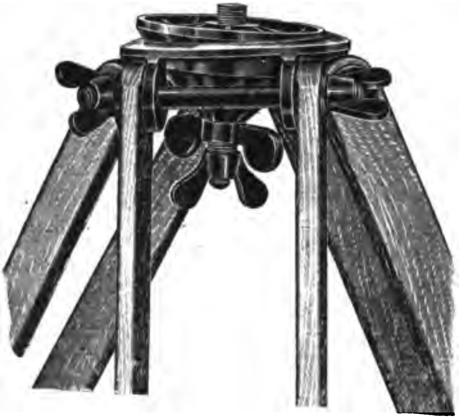

Fig. 1.—Plane table "movement." The upper wing nut secures the table when it has been made horizontal; the lower one clamps it when properly oriented.

In the use of the plane table the following requirements must be fulfilled:

1. The surface of the board should be in a true horizontal plane, that is, the board must be level.

2. The known point on the table should be vertically over the corresponding point on the ground when making a setup at the known point.

3. A known line or meridian of the map should correspond to a similar meridian on the area to be mapped.

Fig. 2 represents a portion of the area to be mapped; in this are the three triangulation points A, *B*, and *C*. The small rectangles represent various positions of the plane table. In position 1 the table has been set up over point *A*, leveled and turned until its North line corresponds with the true meridian. If the plan is a true one, the small triangle, $A B' C'$ should be exactly similar to the large triangle *ABC*, and the sides of the two should coincide, or a line of sight from *A* to *B* should be a prolongation of the line AB'; similarly the line *AC* should be a prolongation of the line AC'. A plane table set up over a known point may therefore be oriented, or placed in proper position, by swinging it until the line of sight through the point at which it is set and the plotted position of another known point strikes the second point.

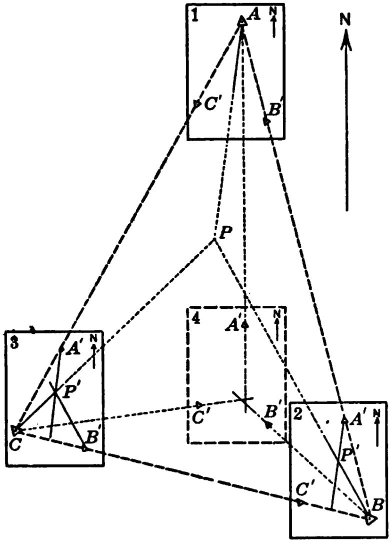

Fig. 2.—Diagrammatic illustration of the use of the plane table.

Suppose it is desired to determine the position of some point, *P*, which is not located on the map. From position 1, Fig. 2, the point *P* is sighted and the line *AP* is drawn on the map; the point *P′* on the map must lie somewhere on this line. Next the table is moved to position 2, over point *B*, and the line *BP* is drawn; *P′* on the map is on this line and also on the line *AP*, therefore it must be at the intersection of the two as shown. This may be repeated at *C* and as many other stations as may be convenient and the point at which most of the lines intersect will be the position *P′* of the point *P* on the map.

This process is called "location by intersection" or "cutting in," and is of especial value in making locations of inaccessible points; rough triangulation may be carried out very rapidly and effectively by this method.

The use which is most frequently made of the plane table in such mapping as I am going to describe is to set up over an unknown point and determine its location.

Referring to Fig. 2, the table is set up in position 4 over an unknown point; the line of sight through the plotted point *B′* and the corresponding triangulation point *B* is drawn on the map, similarly lines *CC′* and *AA′* are produced to the intersection, which is the location on the map of the point at which the table is set. This is called "making a three pointer" or "location by resection." If the three lines do not intersect at one point there results a triangle of error. The discussion of the method of finding an unknown point given three known points, is taken up as the "three point problem," and solutions are given in most text-books on surveying. When the table is oriented by means of a compass the error will usually be small and the operator can tell by inspection which way the table should be turned to give a satisfactory intersection. Other uses of the plane table are combinations of these two and will readily suggest themselves to the operator in the field.

The alidade consists in its simplest form of a ruler or straightedge parallel to which is a line of sight determined by sight vanes. In the form used on the large plane table there is a telescope for the line of sight; such an instrument is shown in Fig. 3.[1] The telescope is fitted with stadia wires, striding level, and vertical arc. For adjustment of the line of collimation the telescope may be turned on its axis through 180 degrees A diagonal prism which may be attached to the eyepiece makes the work of observation much easier when many stadia readings are to be taken. The Beaman Arc also greatly facilitates progress in stadia surveying and should be ordered with the alidade. It is desirable that the telescope have a wide field and some engineers prefer the inverting type.

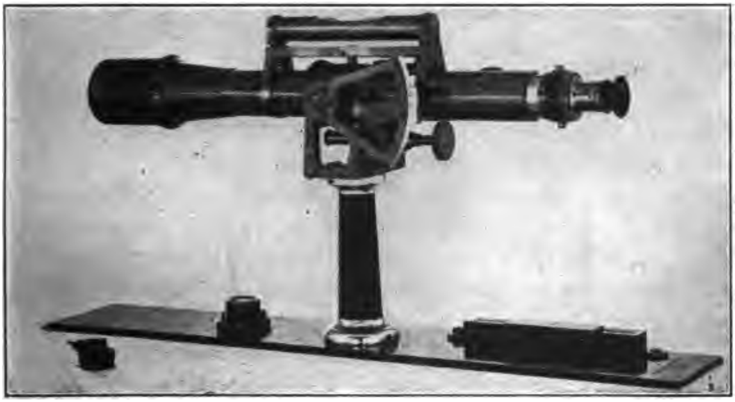

FIG. 3.—Telescopic alidade used on large plane table.

For adjustment of the line of collimation: Set up the plane table firmly and level it, place the alidade upon the table and level the telescope by means of the striding level. Focus either of the wires upon some well defined point from 100 to 500 ft. away and then turn the telescope half way around on its axis. If the wire which is being adjusted has moved away from the point it should be brought back half way with the capstan head screws at right angles to it. If both wires are out they should be made nearly correct before making the final adjustments. For stadia work the stadia wires should be adjusted so that they subtend the proper spaces on the rod at carefully measured distances.

---

[1] Cut furnished by Bausch & Lomb Optical Company.

To find out if the line of sight of the telescope is parallel to the straightedge a line may be laid out on the plane table with a transit that is in good adjustment and a distant object sighted on this line. The edge of the alidade is then placed on the line on the plane table and the same distant point is sighted; the vertical wire should not miss the point appreciably, if it does the same test should be made for a sight of about 2000 ft. (the limit of ordinary stadia readings) to find out if the error is great enough to be taken into consideration in plotting on the working scale. It should be remembered that in locating by the methods of resection and intersection much longer sights will be taken. If the instrument is found to be badly in error it must be sent to the makers, as it cannot be adjusted for this error in the field.

The vertical arc through which the telescope turns is so small that any inaccuracy will be slight compared to the error that may result from the table being out of level. The straightedge should be perfectly flat and the screws which hold it to the telescope column should be firmly in place. The alidade is received from the makers presumably in good adjustment and will stay so for long time unless subjected to very hard usage. When there is reason to believe that it has been injured it should be tested, and in any event should be turned into the makers to be cleaned and adjusted after a season of service.

In leveling the plane table the striding level from the alidade may be used; for orientation a compass needle in an oblong box is provided, sometimes it is mounted upon the straightedge of the alidade. Any compass with a 2 1/2-in. needle will do for this purpose and a convenient one is the geologist's compass, Fig. 17, which has a device for setting off the magnetic variation; when this compass is used the levels on the compass case may be used in leveling the table.

Stadia Surveying.—For ordinary topographic surveying great refinement of stadia method is unnecessary; it may be well, however, to outline briefly the theory of stadia surveying. In Fig. 4 we have:

i = distance between stadia wires.

s = space intercepted on the rod for any given reading.

f = outer or inner focal length of objective.

d = distance to rod from outer focus.

$f+c$ = the "constant" (given for each instrument usually on a card in the carrying case) = distance from axis of the instrument to outer focus.

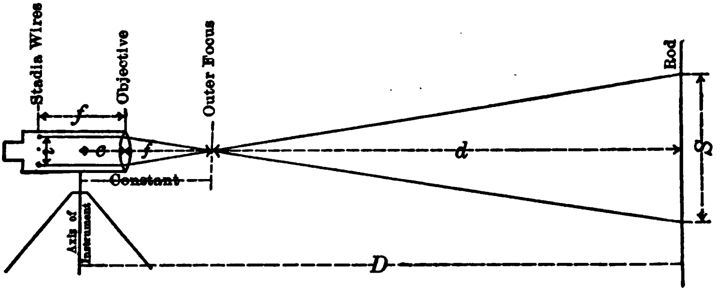

FIG. 4.—Diagram illustrating the theory of stadia surveying.

D = total distance from the axis of the instrument to the rod $= d + (f+c)$.

$$\frac{d}{s} = \frac{f}{i} \text{ or } d = \frac{f}{i}s.$$

The ratio of f to i is determined as follows:

Choose a convenient point from which to measure and set up the instrument so that its center is a distance equal to $f+c$ behind the point. Carefully measure off 100 ft. from the point and establish another point on which to hold the rod. At this distance the wires should intercept 1 ft., upon the rod; if they do not they should be adjusted until they do. The formula given above then becomes $d = 100s$ which is convenient for calculation, since every foot of rod reading means 100 ft. of distance from the outer focus. The total distance, D, is obtained by adding $f+c$ to the observed distance. Since $f+c$ is small it may be neglected except in very close work.

The distance between the stadia wires should be checked for readings of 200 and 300 ft. when convenient. It is well to have permanent points established for this work of adjusting and the wires should be tested frequently.

The rod reading gives the slope distance when reading at an angle and this distance must be reduced to horizontal distance for plotting on the map, and vertical distance for determining difference of elevation. The solution is a trigonometrical problem upon which is based the construction of stadia tables giving horizontal distances and differences of elevation per 100 ft. for angles up to 30 degrees. The common devices for furnishing these figures are stadia tables, stadia diagrams, slide rule, and the Beaman Stadia Arc. Tables for use in the field should be of convenient size to fold and carry in the pocket, and should be mounted on waterproof cloth.

The Beaman Stadia Arc (Reference: "Stadia Surveying," published by W. & L. E. Gurley, Troy, New York) carries two scales; the one marked *H* gives the percentage reduction which must be applied to the observed slope distance to give the horizontal distance per 100 ft. For example, with a rod reading of 640 ft. and the *H* scale reading 3 the horizontal distance will be $640-(640\times.03)=620.8$ ft. The scale marked *V* has the initial graduation 50, this is subtracted from the arc reading (when a whole number on the *V* scale is opposite the index) preserving the algebraic sign. The observed stadia distance is multiplied by the resulting number and the proper sign is retained with the product. The length of the rod between the middle stadia wire and the bottom is added to negative readings and subtracted from positive ones. The result is the difference in elevation between the instrument and the bottom of the rod; this difference is added to or subtracted from the heighth of instrument according to its sign. Example: rod reads 640 ft., *V* scale reads 33, middle wire cuts the rod 7.4 ft. above the bottom, heighth of instrument is 2162.4 ft.

$33-50=-17;\ -17\times 6.4=-108.8;\ -108.8-7.4=-116.2$

$2162.4-116.2=2046.2=$ elevation of new point.

In general in stadia surveying the following points should be observed; the rod should be held plumb and should be in good focus; the instrument should be in good adjustment. It is well not to continue work when atmospheric disturbances are great, especially if accuracy is desirable. When the air is unsteady due to "shimmer" or convection currents, read with the lower wire as far from the bottom of the rod as possible. Stadia wires should be adjusted as nearly under working conditions as possible. With large vertical angles the distance should be read with great accuracy; with small angles on long sights the angle should be read with care.

The stadia rod for use in this kind of mapping should be 10 or 12 ft. long, of light 3/4 in × 4 in. material; it should be painted black and white and need show no divisions less than 1/10 of a foot, Fig. 5 shows a suitable design for such a rod. This will permit readings to within 10 ft. which is about the limit for a self-reading rod at distances over 500 ft. At less distance the reading may be estimated more accurately. Stadia is not used in this work where exact locations are desired, these are obtained by triangulation or the method of resections. The rod should have some sort of device by means of which it may be plumbed accurately; a light iron pendulum set in a case on the back of the rod will do as well as a rod level; the base of the rod should be shod with a light strip of iron. Proper divisions may be painted on aluminium strips of convenient length for carrying; these are nailed to a suitable piece of board for use in the field.

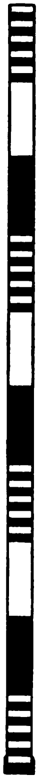

FIG. 5.—Rod for use in ordinary stadia work where great accuracy is unnecessary; smallest divisions represent 1/10 ft.

CHAPTER II

TOPOGRAPHIC MAPPING

It is the writers intention in this and the following chapter to give a concise description of a quick and accurate method of making a mine surface map. The scheme here outlined has been used in mapping properties in the Western and Southwestern States and Mexico; but, while it is especially adapted to arid districts, it can be used with modifications anywhere but in heavily wooded country.

The theoretical discussions have been made as brief as possible, and no attempt has been made to go into the more elaborate methods of topographic surveying, which may be found in any one of several excellent texts.

A mine surface map should show:

1. The astronomic meridian with the magnetic variation line; also the locations of permanent points established by the survey, and the system of the coördinates by which points are located.
2. Property boundaries or claim lines.
3. Mine openings such as shafts, tunnels, and prospect pits.
4. Buildings, roads, railroads, etc.
5. A graphic representation of the natural features of the surface, such as hills, drainage, etc.

This last requirement may best be fulfilled by a topographic map, which shows lines on which all points have the same elevation. Such lines, called contours, are usually drawn at fixed intervals depending on the scale of the map and the nature of the surface of the ground. Any contour on a map of a small area represents the intersection of a horizontal surface with the surface of the ground; or the contour line may be regarded as the shore line of an imaginary body of water in which hills are islands (the contour line will close upon itself), and valleys are straits or embayments. Fig. 6 shows a part of such a map; the hatched portion represents the plane of the 4175 ft. contour. Fig. 7 is a section constructed along the coördinate *N* 1000 of Fig. 6; the parallel horizontal lines represent the planes of the different contours.

A topographic map gives at a glance a general idea of the surface of the ground and its relations to artificial features; it shows, for instance, in Fig. 6, that a claim covers most of a well-known hill and that its Northeast corner is in the "draw" on the other side of the main ridge.

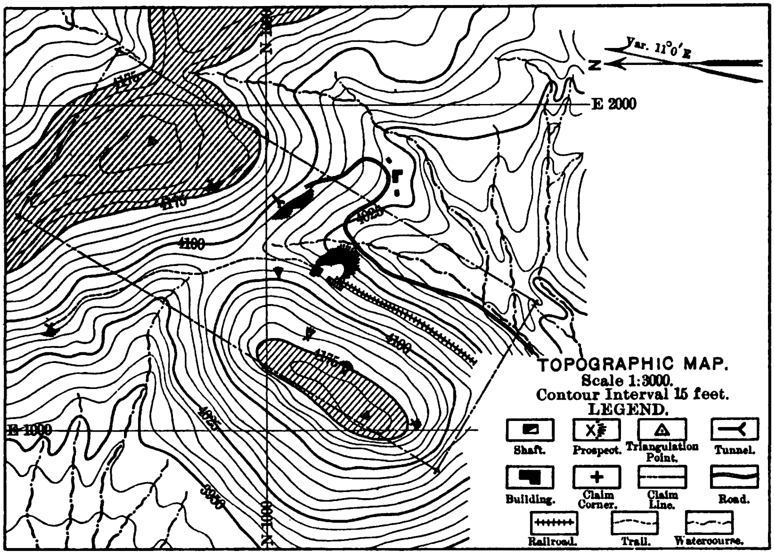

FIG. 6.—Portion of a topographic map. The hatched areas are those which would show above water if the country were submerged to the level of the 4175 ft. contour.

From the map an approximate determination of elevation may be made by simply referring to the contour nearest the point in question, or more accurately by measuring the distance of the point from the nearest contour and comparing it to the distance between contours.

Again, profiles may be constructed from the map along proposed lines for roads, railroads, ditches, launders, or pipe lines, and the most feasible courses for such surveys may be determined without actual field work.

As a basis for geologic mapping a topographic map is very desirable, for the geologist can locate boundaries in the field with reference to the natural features. He can also calculate the probable migration of an outcrop with the dip, or the probable location of a vein at a given depth below an outcrop the elevation of which may be determined with sufficient accuracy from the map.

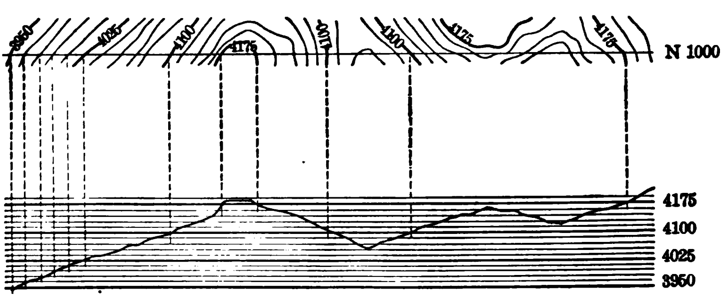

FIG. 7.—A section made from a topographic map by direct construction.

Since the map is based on a system of triangulation points the latter serve as permanent points from which to start traverse surveys. Further, any new point may be located by triangulation, thus obviating the use of traverse lines. In locating a shaft, for instance, a point near the shaft may be occupied as one point of a triangle, of which the other two are permanent stations. When the three angles have been read and the triangle solved the position of the new point is determined with an accuracy dependent on the accuracy of the triangulation system. Usually the results thus obtained will be more satisfactory than those of a traverse survey, especially in rugged country. One man with a transit can do practically all the work of location, thus dispensing with the other members necessary to a transit party. This method has been successfully used in the exact location of drill-holes which had been laid out by a traverse which did not close.

Making a Topographic Map.—The following description applies to work on an area of average size, say, 4 square miles; the methods are such as to afford a considerable degree of accuracy.

The first step in the survey is to lay out a triangulation system to be constructed upon a carefully measured base line. The general requirements for such a system are as follows:

1. At least three triangulation points should be visible from from any fairly prominent point in the area. If the scale of the map is such that several sheets will be required to cover it (regarding each sheet as 24 in. × 30 in. in size), at least three points should be visible from any fairly prominent point in the area covered by each sheet.

2. No triangle should have an angle of less than 20 degrees; equilateral triangles should be approximated as nearly as possible.

In determining the locations of the triangulation points the position of the base line should be considered so as to be sure of one or two good triangles having the base as one side. A little preliminary work with a small compass will often save trouble, as the angles may be read roughly and a sketch of the system plotted.

The general reconnoissance of the ground completed, the first step in the actual work is to select a favorable site for the base line. The chief requirements for it are:

1. The ground should be as nearly level as possible, or should have a fairly uniform slope.

2. The length of the line should be near that of the triangle sides.

In rugged country a short base is preferable to a long one, since it can be more accurately measured. With a short base several intermediate triangles of sides to correspond to the length of the base-line may be made and thus a longer line for the main system may be determined. In Fig. 8 *a–b* represents the base, from which the points, *c*, *d*, *e*, *f*, and *g* may be located by triangulation. The distance between *d* and *g* will then be known and may be taken as the base *A–B* of the main system of triangles.

When the site for the base-line has been determined, permanent points should be established at the ends of the line, and since flat spaces do not as a rule expose bed-rock, the most satisfactory point may be obtained by digging a hole and setting the iron or brass pin in concrete, which should be built up to within a couple of inches of the top of the rod. On the cross-section surface of the rod the base line should be indicated as a diameter, at right angles to it another line should be scratched. The intersection of these two serves as a point over which to set up the transit.

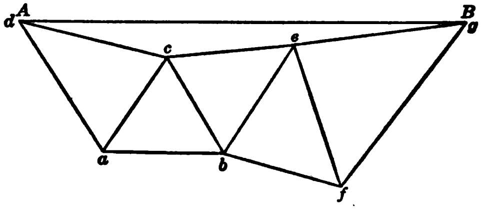

FIG. 8.—The base line *AB* is obtained from the triangulation system based upon the relatively short line *ab* which can be accurately measured.

Measurement of the Base-line.—Beginning at one of the permanent points the line is run out with a transit and a preliminary measurement of it is made, by means of which 1 in. × 2 in. stakes are set every 25 ft., the 2-in. dimension being at right angles to the line and bisected by it. For the 100 ft. stakes 2 in. × 4 in. material is used with the 4-in. dimension in the line and the 2-in. dimension bisected by it. All stakes are set just firmly enough to hold them in place.

A line of levels is now run over the base and the profile is plotted. If the ground is practically level a horizontal line may be determined and the stakes driven down to it; if the slope is uniform the stakes may be driven down to that line. But the chances are that the slope line will be broken, in which case the stakes between the points of change should be set to conform with the local slope.

Fig. 9 shows the slope lines and the stakes set as described.

When the stakes have been lined in and set at satisfactory levels the 100 ft. stakes are capped with strips of tin on which the line is scratched. On top of the intermediate stakes shingle nails are put to serve as guides to the tape.

The measurement of the base-line should be made under temperature conditions as nearly uniform as possible. Such conditions obtain on cloudy days or when the sun is below the horizon.

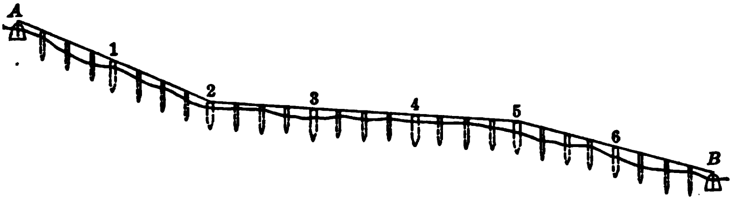

Fig. 9.—**Diagram showing how stakes are set and slope lines established in making base line measurements.**

A 100-ft. tape which has been standardized (is known to measure exactly 100 ft. at a certain temperature, under a given tension or pull) is the most satisfactory measure for a base-line of this type. The tape should be provided with a handle at the zero end and a ring for a spring balance at the other end. Balances made especially for this purpose may be obtained from the instrument makers. A Fahrenheit thermometer reading to degrees should also be provided.

In very accurate work, such as that done by the Geological Survey, special devices are used for stretching the tape, but for this kind of work such devices are not necessary.

In making the measurement the tape is stretched over the zero point of the base-line and the first of the 100 ft. stakes, and is put in the guides on the supporting stakes. At the zero end one man holds the tape and keeps its zero mark in coincidence with the zero of the base; another man is at hand to give the signal when the measure is to be taken. At the other end one man holds the spring balance and applies as nearly the proper tension as possible, while a second observer is ready to mark the 100 ft. point on the tin strip. At the signal to measure, given when the zero point of the tape is on the starting-point, the recorder near the middle of the tape length, records the measure, temperature, time of day, and tension. This is repeated for all the stations until at the last one the observer reads the tape carefully, as the last measurement will be a little more or less than 100 ft.; the reading is taken with a scale which is graduated to 500 or 1000 parts of a foot.

The measurement should be made two or three times and if the results check within 0.04 (error of 1:50,000 for 2000-ft. base-line) of a foot the mean may be taken after the proper corrections have been applied.

Base Line Corrections.—The tape is given as standard under certain conditions of temperature and tension. By making measurements under very nearly the standard tension, this correction may be avoided. The temperature correction is made by taking an average of the readings for each section and finding the difference between this mean temperature and the standard. The correction in length of the base-line is the product of the difference in temperature and the coefficient of expansion of steel (the fraction by which the length changes for a variation of 1° F. = 0.0000063596) and the measured length of the line; or expressed by formula:

$$C_t = (t_s - t_m) L \times 0.000006.$$

Where C_t is the correction for temperature,
t_s is the temperature for which the tape is standard,
t_m is the temperature (Average) for the measurement,
L = is the measured length of the line.
All temperatures are expressed in degrees Fahrenheit.

The correction is added or subtracted according as the change is a lengthening of the tape with increase or shortening with decrease of temperature.

BASE LINE MEASUREMENT AND CORRECTIONS

TAPE STANDARD AT 62° F. AND 20 LB. TENSION

Supports every 25 ft. Tape's Weight is 0.0145 lb. per foot

Time	Sta. No.	Slope distance	Ten-sion lb.	Temp. F.	Diff. of elev. $=e$	C_t	$C_s=\frac{nl}{24}\left(\frac{wl}{t}\right)^2$	$C_h=\frac{e^2}{2S}$	$C_h+C_s+C_t$	Corrected length.
P. M. 8.00	A to 1	100.000′	20.0	70°	A to 2	=200×(+8) ×0.000006	$=\frac{8\times25}{24}\left(\frac{0.0145+25}{20}\right)^2$	$=\frac{8.24^2}{400}$		
8.05	1 to 2	100.000′	20.0	70°	8.24′	=+0.0096	=−0.00273	=−0.169	−0.162	199.838
8.12	2 to 3	100.000′	20.0	71°		=300×(+9)	$=\frac{12\times25}{24}\left(\frac{0.0145\times25}{19.5}\right)^2$	$=\frac{2.56^2}{600}$		
8.15	3 to 4	100.000′	19.5	70°	2 to 5	×0.000006				
8.27	4 to 5	100.000′	19.0	72°	2.56′	=+0.0162	=−0.00432	=−0.0109	+0.001	300.001
8.32	5 to 6	100.000′	20.0	72°	5 to *B*	=200.167×(+10) ×0.000006	$=\frac{8\times25}{24}\left(\frac{0.0145\times25}{20}\right)^2$	$=\frac{5.62^2}{400}$		
8.40	6 to *B*	100.167′	19.5	72°	5.62′	=+0.012	=−0.00273	=−0.079	−0.069	200.098 699.937

C_t = temperature correction. C_s = correction for sag. C_h = correction for slope.

FIG. 10.

Fig. 10 shows the method of recording and reducing base line measurements.

Since the tape is supported on stakes there is some shortening of the measurement due to sag under its own weight; the formula for this shortening is.

$$C_s=\frac{nl}{24}\left(\frac{wl}{t}\right)^2$$

Where n is the number of lengths into which the tape is divided by the supports,

l is the distance between supports,

w is the weight of the tape per foot, in pounds,

t is the tension in pounds under which the measurement is made.

With a 100-ft. tape, supported every 25 ft., weighing 0.0145 lbs. per foot, measurement made under a tension of 20 lb.:

$$C_s=\frac{4\times25}{24}\times\left(\frac{0.0145\times25}{20}\right)^2=0.0136.$$

In twenty tape lengths or 2000 ft., this correction would be 0.027 ft.: it should be subtracted to give the correct distance.

When the slope distance is known, and since the difference in elevation of the ends of the slope is known from the profile, the reduction to horizontal may be made according to the formula $h=\sqrt{s^2-e^2}$

h is the required horizontal distance,

s is the measured, or slope distance,

e is the difference in elevation between the ends of the slope.

All these distances are expressed in feet.

Since the slope distance is usually given to three decimal places it is awkward to handle as a square; a more convenient formula is the following:

C_h is the correction necessary to reduce the slope distance to the horizontal, then using the symbols as given above:

$C_h=s\text{-}h$, or $C_h\text{-}s=\text{-}h=\sqrt{s^2\text{-}e^2}$

$C_h{}^2\text{-}2C_hs+s^2=s^2\text{-}e^2$

s^2 may be canceled and C_h^2 is so small that it may be neglected, whence $2C_hs = e^2$, or $C_h = \frac{e^2}{2s}$.

The sum of the horizontal distances thus obtained is the length of the base line. The mean of the lengths according to three measurements corrected for temperature and sag and reduced to the horizontal, is used in the computation of the triangulation system.

Errors in Base-line Measurements.—Johnson says (Theory and Practice of Surveying, p. 497):

"For an accuracy of 1 in 50,000 the mean temperature of the tape should be known to the nearest degree Fahrenheit, the slope should be determined by stretching over stakes, or on ground whose slope is determined, and the pull should be measured by spring balances. The work could then be done in almost any kind of cloudy weather." By taking the mean of several measurements which check within the error allowable for an accuracy of 1 in 50,000 the error in the measurement of the base will be of practically no consequence in triangulation of this type.

Triangulation.—All triangulation points, at least those of the primary system, should be permanent points which may be made by setting suitably marked brass or iron rods in cement in holes drilled in solid rock where possible. The rod need not project more than 2 or 3 in. For sight rods flag staffs of about 1.5 in. in diameter, painted red and white on alternate feet may be used. They should be of measured length, and shod with a piece of pipe which will fit over the pin of the permanent point so that the base of the staff rests on the top of the pin. The staff should be set perpendicular and held so with guy wires. Flags should be of sufficient size to be seen without difficulty by the unaided eye from other stations; they should be white or red to contrast with the background against which they will be seen. A white flag shows up well against the sky but it is very hard to pick out when backed by white limestone or snow.

Reading Angles.—For measuring angles an ordinary transit is used; the instrument should not be too light, one with a 5-in.

compass needle is preferable, and vernier reading to minutes, the finer graduation is desirable for accurate work. The limb should be graduated from 0 degrees to 360 degrees reading in both directions. The instrument should be in good adjustment.

The work is done on cloudy days or early in the mornings to avoid distortion due to convection currents in the air.

Readings are taken according to some regular plan and are carefully recorded as read. For instance, the angle is repeated until the entire circumference of the limb has been covered. Of these readings the first and second and the total are recorded, then the average angle.

One set of readings is taken with the telescope direct, turning the angles from left to right; another set is taken turning the angles from right to left. The telescope is then inverted and the readings in both directions are repeated.

At each station the height of instrument is recorded and vertical angles are read to the tops of the pins or the tips of the flags of all other stations in sight. These readings should be made with the telescope both direct and reversed, and recorded with the proper + or – signs.

Fig. 11 shows a form of notes which may be used for these readings.

At △ *A*		1	2	Total (10)	Vert. >
B to *C* *H. I.* 4.12′	*D–LR*	35°15′30″	70°30′30″	352°33′20″ 35°15′20″	*A* to *B*, +4°10′ to top of flag.
C to *B*	*D–RL*	35°15′20″	70°31′00″	352°34′00″ 35°15′24″	A to C, –2°20′ to iron pin.
B to *C*	*I–LR*	35°16′00″	70°31′40″	352°35′00″ 35°15′30″	A to B +4° 12′ top of flag.
C to *B*	*I–RL*	35°15′30″	70°30′40″	352°34′10″ 35°15′25″	A to C –2° 17′ to iron pin.
		Average value < *BAC* = 35°15′25″.			

Triangulation Notes.

D = Telescope direct. *I* = Telescope inverted. *LR* = Left to right. *RL* = Right to left.

FIG. 11.

Calculation of Triangles.—All calculations in connection with the base line measurements, observations for true meridian, and solution of triangles, should be made in blank books kept in duplicate, and all computations should be checked by two computers working together. The use of seven place logarithmic tables greatly facilitates these calculations.

The first step in the calculation of the triangles in the adjustment. The sum of the angles of any plane triangle is 180 degrees, but it is very rare in practice to have a triangle close exactly—the sum of the angles will be a little too large or too small. This discrepancy must be distributed among the three angles, which may be done with sufficient accuracy by dividing the error equally or if it is assumed that the error is due to inaccuracies in sighting and clamping the plate, the smaller angles should have the larger portion of the correction, since in repetitions over the entire circumference of the circle, they require more pointings of the telescope and more clamping and unclamping, thus affording greater opportunity for error.

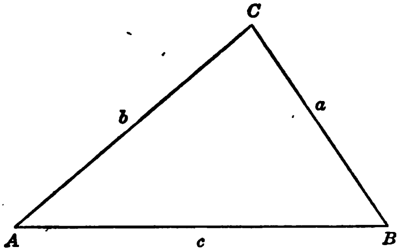

FIG. 12.

Solution of the Triangles.—The solution of the triangles is started with one of them which has the measured base line for one side. All the angles are known and the simplest formula is $a:b::\sin A:\sin B$; where a and b represent the sides opposite the angles A and B, as shown in Fig. 12. This formula becomes

$$a=\frac{b\sin A.}{\sin B}$$

Determination of Elevations of Triangulation Points.—The triangulation points serve as the starting-points for further surveying operations, and it is, therefore, desirable that their elevations as well as their locations be known. The most exact method of determining elevations is by means of checked level lines; but leveling is slow and costly work, especially in rough country. For most practical purposes it will be found satisfactory to determine the elevations by means of the vertical angles which have been read at all the points and recorded together with the heights of instrument. A careful line of levels is run to the base line or to some convenient triangulation point, and with this as a starting-point calculations may be made for all the points of the survey.

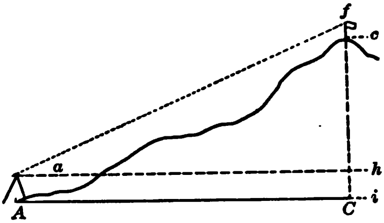

FIG. 13.

It may happen in reading the vertical angles that the pin at the other station cannot be seen, in which case the angle should be read to the tip of the flag staff. The observer should be careful to record this fact.

In Fig. 13 *AC* represents the side of the triangle *ABC*, "*a*" is the average vertical angle read to the top of the flag "*f*"; "*cf*" is the height of the top of the flag above the iron pin; "*hi*" is the height of instrument above the pin at *A*, the elevation of which is known. "*Cc*" is the difference in elevation sought.

$$\frac{fh}{AC} = \tan a \text{ or } fh = AC \times \tan a.$$

Since *AC* is known from the solution of triangle, *ABC*, *fh* is easily obtained, and $fh - cf + hi = Cc$, which is the difference of elevation sought.

This elvation is checked against the one obtained by reading from station "*c*" back to *A*; the average of the vertical angles read with the telescope direct and inverted is used for each station, and the average of the differences in elevation as determined from both stations is taken as the final difference in elevation. This may be checked by determining the elevation of "*c*" with respect to some other point of known elevation; it is well to calculate a new elevation from at least two old points.

To determine the total difference of elevation:

With a positive vertical angle, the height of flag is subtracted from, and the height of instrument is added to the value obtained from the tangent calculation.

With a negative vertical angle, the height of instrument is subtracted from and the height of flag is added to the value obtained from the tangent calculation.

The triangulation system as a whole may be checked by measuring another base line at the opposite end of the system from the main base; when this has been done the second base is made the side of a triangle and its computed length is checked against the measured length. This is hardly necessary with a small system.

Plotting the Triangulation System.—Preparatory to plotting the triangulation system, an observation for the true meridian should be made and checked and referred to some convenient line of the system, the base or a triangle side. Next, a point is determined upon as the starting-point for a system of coördinates; if a triangulation point is not convenient, some other point should be carefully located by triangulation.

Fig. 14 illustrates the coördinate system of location. The point marked *oo* is the "origin"; the lines *5E*, *5N*, etc., are drawn north and south, and east and west, at stated intervals. The distance that a point lies north or south of the east-west line through the origin is called its "northing" or "southing" as the case may be, or may simply be spoken of as the "latitude"; similarly, there are "eastings" and "westings," or "departures." Thus point "*A*" would be described as 7 north, 3 east, (*7N*; *3E*), and would be said to have a northing of 7, easting of 3; or latitude 7*N*; departure, 3*E*.

The bearings of the triangle sides are figured from the true meridian.

All the angles of the system are known, also the lengths of the triangle sides, from which data it is possible to calculate the latitude and departure of each triangulation point as would be

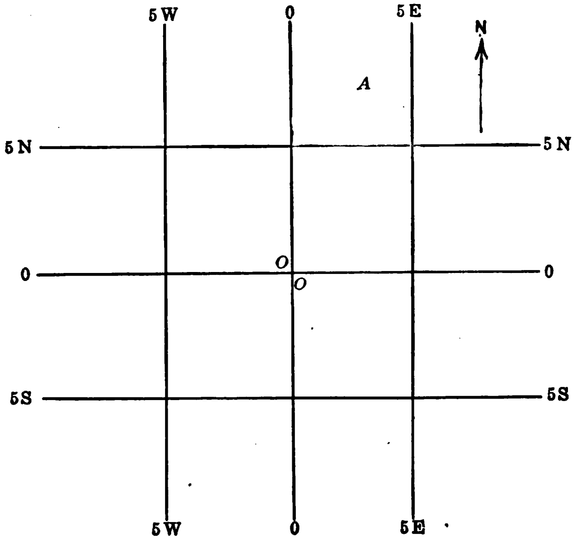

FIG. 14.

done for an ordinary traverse, using as a starting point one the coördinates of which are known. The coördinates of all points should be computed in the calculation books and tabulated; also a sketch of the system should be made to scale and put in the book, together with descriptions of the locations of all the points. These computation books thould be so complete and legible that any engineer could, at any future time, have all the data of the triangulation of his disposal.

If for convenience in starting subsequent surveys more points are desirable, in addition to those of the primary system, such points may be put in at any time with such accuracy as the work may demand by further transit-triangulation or by the method of intersection with the plane table, which is described elsewhere.

CHAPTER III

TOPOGRAPHIC MAPPING (Continued)

With the triangulation system as a basis the next question which arises is that of filling in the details on the map, locating the various buildings, claim corners, etc., and mapping the ground surface. Such work may be done either by transit and tape traverse or by stadia. The stadia method is accurate enough for all practical purposes and may be employed either with a transit or with a plane table and alidade; topography may be mapped by either method.

Transit vs. Plane Table.—The method of working with a transit is to run a traverse from the nearest triangulation point and establish stations from which stadia measurements are made and recorded in a note-book together with such sketching as may be deemed necessary. From these notes the map is then worked up in the office. The chief advantage that the method has is that it may be employed in rainy weather with no other precaution than that of keeping the note-book dry.

In all other respects it is inferior to careful plane table work, especially for mapping roads and topography. The actual drawing of the map is done in the office and even with copious notes it is hard to give an even fairly correct representation of features which are no longer seen. The mapping of the topography consists chiefly in the location of the lines of equal elevation or contours, and this can be done with any degree of accuracy only when the country to be mapped is right before the eyes of the mapper and he can see the relation of his points of known elevation to the rest of the surface. Transit topography is wooden and inaccurate at its best. Plane table topography is much more accurate, while it depends on the skill of the topographer whether or not the map gives a vivid and graphic representation of the surface.

Assuming, that the plane table will be used in the map work, reference may be made to Chapter I, for a description of the instrument and its use. The first thing to be considered preparatory to starting mapping in the field is the question of scale. No hard and fast requirements can be laid down in this matter, since so much depends upon the character of the ground to be covered and the time to be given to the work. Before deciding upon the contour interval some preliminary mapping should be done in localities which seem typical of the area as a whole.

Preparation of Working Sheets.—The choice of scale and contour interval will be determined by the special requirements of the area. The following instances may be of some value in deciding this question: For an area of about 4 square miles of moderately rough country a scale of 1 in. to 300 ft. was used, with a contour interval of 25 ft.; for an area with low hills and gentler slopes the interval should be lessened to 15 ft.

For an area of less than 2 square miles a scale of 1 in. to 150 ft. was used; 1 :2000 is also a good scale for smaller areas. With either of these scales the interval may range from 10 to 15 ft.

When the natural features are on a large scale, with considerable difference of elevation—steep cliffs and deep gorges—and the area to be covered is quite extensive, the scale may be made 1 in. to 500 ft., or 1 :5000, with a contour interval of 30 to 100 ft., depending on the steepness of the slopes.

In general it may be said that the contour interval should be such that the map will not appear crowded or its legibility obscured by the contour lines. The average space between the lines should be from 1/4 in. to 1/2 in.

The best paper for use on a plane table when the map is to be on the board for some time, is a fairly heavy linen-mounted drawing paper. This paper, especially if it is bought in rolls, should be allowed to dry out thoroughly under the conditions to which it is to be subjected in the field. In laying out the working sheets in case there are to be several of them to the map, they should be placed upon a large table and over-lapped a couple of inches from their working edges to permit of work being transferred from one to the other in joining them for the final map. For convenience in locating points the coördinate system (p. 23) is usually adopted in some form. It is most convenient to assume that the *00*, or origin, lies to the southwest of the area mapped. That means that the point from which computations are started is called, for instance, 3000*N*–2000 *E* instead of *OO*; then we have to do only with the "northngs" and "eastings." The lines should be about 4 in. apart and should be plainly numbered.

Coördinate lines should run true north and south, and east and west; they should be ruled on the working sheets with the greatest exactness, using a long steel straightedge. The lines drawn at right angles to those first laid out should be parallel to a line made perpendicular to the first set by means of a good right triangle, and the perpendicularity should be checked by geometrical construction or measurement.

The next step is to plot the triangulation system, checking the locations of the points by bearings and lengths of the triangle sides. Triangulation points should be marked with a triangle —△. If desirable the coördinate lines and the points may be inked in with black drawing ink.

The plane table board has thumb screws at the corners and on the sides to hold the sheet; a small square opening is cut in the sheet about the point where each screw goes through. This is to allow the sheet to expand and contract and to permit wrinkles to be smoothed out.

Field Work.—In going into the field the topographer carries the alidade either in its case or by resting the standard against the inside of his forearm and grasping the end of the straightedge with his hand. The board is carried on the back by means of shoulder straps and should be placed in the case with the map away from the back.

The rodman carries the rod and tripod, unless there is a third member in the party. By taking a man to record (*i.e.*, figure elevations and corrected distances from the readings taken by the topographer) the work may be carried on much faster.

Work is started by setting up the table over some known point, or some convenient point, the location of which must be determined by the method of resection. It is not necessary for the topographic work that the table be set exactly over the known point by means of a plumb bob.

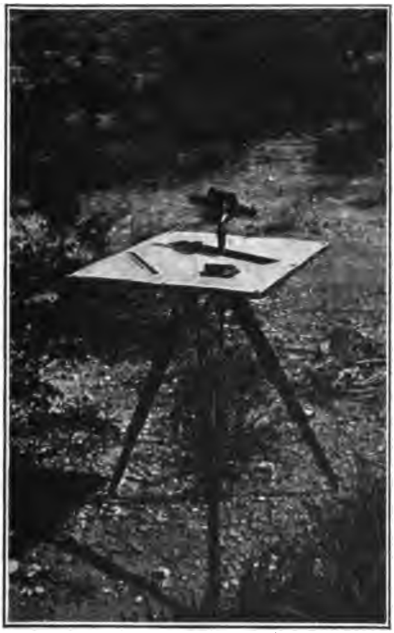

FIG. 15.—Large plane table set up ready for mapping. On the table are the alidade, compass, and scale.

In making the setup, Fig. 15, the tripod is set firmly in place, the board is screwed to it, and the movement nuts are loosened until the table tips easily in any direction; the table is then made as nearly level as possible by eye and oriented roughly by means of the compass. The next step in the setup is to level the table accurately by means of the striding level; this is done in two directions at right angles. Movement of the board is accomplished by tapping the edge with the fingers. When the table is level, it is oriented exactly by compass and if the setup is at a known point the orientation is checked by sighting some other known point.

If the point is not known its location is obtained by the method of resections; the straightedge of the alidade is placed on some known point of the map and the same point on the ground is sighted, a light pencil line is drawn along the straightedge about where the observer thinks the point should fall on the map. This is done three or more times and the point at which most of the lines intersect is marked as the location of the table on the map. Next a point of known elevation, preferably one of the triangulation stations, is sighted; the vertical angle is read and the horizontal distance is scaled from the point of the setup on the map to the point sighted. The slope distance may be calculated from the stadia tables and the difference in elevation given in the table is then multiplied by the slope distance (expressed in hundreds) to give the total difference of elevation between the new point and that sighted. The new elevation obtained in this way should be checked by readings to two or more points.

The topographer is now ready to begin mapping. He lays out a course for the rodman to cover, indicating perhaps fifteen or twenty points, which should include points of change of slope, turns and junctions of stream beds, low points of saddles, hilltops, etc. These for fairly accurate work should lie within a radius of 1000 ft. As the rodman gives the successive points his course may be controlled by a set of signals previously agreed upon, and he may also signal the points he is locating, such as monuments and prospects.

The topographer sights and reads the rod, calling the reading to his recorder, and sets the cross hair on the top, or preferably, the bottom of the rod. He then signals the rodman to go to the next point and reads the vertical angle; from this and the rod reading the corrected horizontal distance and the elevation of the new point with respect to the instrument are calculated. The distance is plotted on the map and the elevation of the point is written in small figures near it.

The rodman should be on the lookout for new points favorable for plane table stations and when be finds one the rod should be held on a stake or stone and the place so marked that it can easily be found again. When such a point is being located the rod reading should be made twice and the elevation of the new point calculated carefully. On occupying a new station of such a plane table traverse line the location should be checked by sights on such triangulation or other known points as may be visible.

When enough points have been located to "control" the area, that is, to give the topographer some idea of the relation of the various points of prominence and their elevations, he begins to draw in the contours; he interpolates between the elevations on uniform slope for the location of any particular contour, and with careful attention to the surface before him, he endeavors to visualize the location of the line and represent it as nearly as possible upon his map. Accurate sketching comes with practice, especially if the observer has any talent for drawing; as he becomes more expert the number of points required for the control may be cut down, but for the beginner the more numerous the points, the more accurate will be the work.

The map should show stream beds and branch water-courses, exact outlines of open cuts, prospect pits, roads, etc. The more points located, the more accurate will be the topography, and the more valuable the map for subsequent work, such as geological mapping.

The work should not be hurried, at least not until the mapper has a fair idea of the problems which confront him. In hot countries with brilliant sunlight the topographer should not work too long at the instrument as his eyes become tired and his drawing suffers in consequence. In such places it is well to have a recorder who can take his turn at the instrument.

In learning to do topographic work with the plane table the best plan is to start as recorder for some one who is proficient in the work. In this way an opportunity is given to see the country and just how it is represented on the map. The recorder's work consists chiefly of making the calculations for corrected distances and the elevations of new points located by stadia or by "cutting in." The first figuring that he does upon starting work from a setup, is to calculate the elevation of the working station as detailed above. This elevation is then written at the top of the computation sheet and becomes the basis for figuring new elevations. The topographer calls the rod readings, as, for example, "Distance 760 ft.," or if he is reading between only one of the stadia wires and the cross wire, "Distance 760, taken twice," in which case the recorder writes 1520 on his computation pad. The topographer then gives the reading of the vertical angle, "Plus (or minus) angle, 6° 20′, top (or bottom) of rod." The recorder puts down the readings as they are given and then turns to his tables. In the tables are given the horizontal distances corresponding to the slope distances for the various angles. Usually it is most convenient to subtract these distances from 100, finding the difference for the given angle for 100 ft. of slope distance. The rod reading is pointed off in hundreds (as 15.2 for the above reading), and multiplied by the difference, giving the total correction which must be subtracted from the slope distance as read to give the horizontal distance. Similarly, the difference of elevation for 100 ft. for the given angle is used to multiply the slope reading for the total difference of elevation.

In case of a plus angle, when the reading is to the top of the rod, the length of the rod must be subtracted to give the difference of elevation between the instruments and the point at which the rod is held.

For a negative angle the length of the rod is added to the total difference in elevation.

For the actual elevation of the new point, the difference in elevation is added to, or subtracted from, the elevation of the instrument, according to whether the angle is plus or minus.

In setting up the table over a point of known elevation, the recorder adds the height of instrument above the point to get his working elevation. In case a point is located by "cutting in" the topographer scales the horizontal distance from the map. The recorder divides this by the horizontal distance for 100 ft. for the given angle, and determines the slope distance with which he proceeds as described above for the elevation of the new points.

The recorder calls the corrected distance and the elevation for each new point to the topographer, who plots them on the map. It is not necessary to save the computations made in the field, since the record is all kept upon the map. The recorder can often assist the topographer by watching the rodman as he takes up new positions, while the topographer is engaged in sketching; on areas where there is much vegetation this will save time, for it is often difficult to locate the rod when only the upper portion is visible. If there is not a recorder in the party, the topographer does his own calculation, usually figuring upon the cover sheet on the plane table board.

It is desirable but not necessary to have a rodman who understands the purpose of the work. If he does he can often give additional readings which will facilitate mapping, or he may do sketching or measurement which will make the work more accurate. As an instance of this in an area where there were narrow canyons with steep walls, the rodman worked along one bank giving the course of the stream, and signaled back the width of the canyon and the distance to its bottom whcih he measured with weighted tape. Boys without any training, however, do well enough for all practical purposes and as they gain experience frequently acquire remarkable aptness for the work, and can rod out a circuit without any directions from the topographer.

In instructing a rodman as to his work, the necessity of holding the rod plumb and steady must be emphasized. Besides the signals necessary to control the rodman, it is also well to agree upon others which he may give to indicate whether the point at which a reading is taken is a claim monument, prospect pit, shaft, or stream bed. It often happens that the instrument man cannot see the bottom of the rod and so cannot tell what to show on the map. When the rod is in part hidden by vegetation, it may be necessary to raise it and hold it steady while a reading is being taken; if the amount of elevation, say 3 ft., has been decided upon, it is easy to allow for this in calculations. Raising a rod in this way is technically known as "booting it" and is sometimes relied upon when the rod is out of range.

As a rule, it may be said that distances should not be read over 1000 ft. or 1500 ft. for accurate work, and of course with a 10-ft. rod 2000 ft. is the limit reading with the half stadia interval. On the whole, it is much more satisfactory to make the radius smaller, since it is then possible to talk to the rodman and distances may be read more closely.

As was suggested above, in the topographic work, an "artistic" eye is greatly to be desired, provided it does not lead to sweeping generalizations in mapping. Sometimes a very beautiful map which looks like the country at a casual glance is found to be very inaccurate as to detail when gone over in subsequent work, such as geological mapping. Of course, there is a limit to the amount of detail which may be profitably shown, but it is better not to have so much than to have it inaccurate in the essential features. Points which can be easily located, such as stream beds, should not be put in too sketchily, for in doing later work it is annoying to find something which has been accurately located falling on the wrong side of a natural feature, such as a stream or ridge top. This also makes it difficult to read a map closely and shakes the confidence of the user in the accuracy of the work as a whole.

Field Outfit.—Flat boxwood scales graduated on both sides to the exact scale to be used are the most convenient for this work; 7H or 8H pencils are used to prevent smudging, and soft erasers are most satisfactory for general work.

Over the map should be put a "cover paper" of dark green to lessen the glare on the eyes.

In hot dry climates a large umbrella, such as is carried on delivery wagons, may be used to afford shade. It should be shod with a pointed ferrule and guyed in place with wires. It will considerably increase the topographers efficiency, and unless many changes of station are made, will not be hard to manage.

The tables used for making the stadia reductions in the field will be found in the hand-books on surveying, but they are usually hard to use in this form. The best plan is to get them in pamphlet form and mount the pages on cloth, forming a folder which may be referred to more readily in the course of the work. Various diagrams have been made to give these reductions graphically and the stadia rule is another convenient method of obtaining them. The Beaman Stadia Arc is also a device for giving these reductions; it is described in Chapter I, and greatly facilitates the work.

Office Work.—With plane table mapping, the office work is cut down to the inking in of the map and preparation of a suitable tracing or copy. Fig. 6 gives a partial set of cartographic symbols which are used on the final map. Contour lines are usually inked in brown, water-courses in blue, and artificial features in black. A contour, or swivel pen, is a great help in the inking when the contours are not too close together; also a double, or road, pen will add greatly to the appearance of the map if there are many roads to be shown.

It has not been attempted to go into detailed theoretical discussion or to describe alternative methods. Anyone who wishes to look up methods more refined or to find thorough discussions of the theory involved, may do so in any of the standard texts, among which are "Topographic Surveying," Wilson; "Manual of Topographic Methods," Gannett (Monograph XXII, U. S. G. S.); "Theory and Practice of Surveying," Johnson; and especially for the Beaman Stadia Arc, "Stadia Surveying," published by W. & L. E. Gurley.

CHAPTER IV

GEOLOGIC MAPPING

General Surface Mapping.—A geological surface map should show the following things:

1. The boundaries of the various rock formations; the strike and dip of the beds in sedimentary rocks, and of lines of schistosity is schists and gneisses.
2. The lines of faults, with their dips, and the direction and angle of fault striæ. Zones of crushing and brecciation also might be included here.
3. The outcrops of ore-bodies and ore-bearing formations. The former should be represented as graphically as possible, both as to outline and the type of mineralization. Dips should be indicated wherever obtainable.

In addition to the purely geological data it is very desirable to show the lines of the claims, and the outlines of the principal underground workings. The general requirements for the base map have been set forth in detail in previous chapters on topographic mapping.

When such a geological map is completed it shows the relations of the formations to the property lines and the surface features. It permits of the comparison of the surface geology with that of areas developed underground, which comparison becomes very important when the underground geology has been worked up in detail. With the aid of a complete geological map the various problems encountered may be studied in their entirety and thus important relations are often deduced. In connection with a topographic map the geologic map gives a complete representation of natural conditions. It also forms a basis for measurements of outcrop migrations, vein migrations with depth, displacements due to faulting and so on.

Base Maps.—A topographic map is the most desirable basis for geological work because it enables the geologist to tell about where he is simply by glancing at his working sheet; he can also sketch geologic features with reference to prominent surface points.

The map should have a system of coördinates laid out according to the true meridian, and coinciding with the system used in mapping the mine workings. This will greatly facilitate the work of comparison of surface and underground geology.

The scale used will depend upon the nature of the geology to be mapped. If the boundaries are well marked and not complicated, the formations few in number, and the vein and fault system not complex, a relatively small scale, say 1 in. = 500 ft., or even 1 in. = 1000 ft., will do, especially if the area to be covered is large. A quite large scale would be 1 in. = 100 ft., and would only be necessary with a small area of very much involved geology, or in case the mine workings had been mapped to such a scale. The average scale, quite satisfactory under most conditions, for properties of moderate size may be given as 1 in. = 250 ft.

Working Sheets.—The best working sheets are white prints, made either from a negative of one of the brown print papers or directly from the tracing on a white printing paper. A working print should not be brittle, as is the case with some of the papers requiring an acid fixing bath. A tough blue print paper over-printed from a dark negative makes a good working sheet. The advantage of the white print papers which print direct from the tracing, is that the error in scale due to shrinkage is much less than where a negative is used. The negative must also be treated with a fixing solution, as must all brown process prints; whereas, with the direct white print it is only necessary to wash it with water.

Methods of Field Work and Equipment.—Rough mapping may be done by tying to claim corners or other points marked on the map. In this work directions are taken by compass sights and distances are measured by pacing. Such work may be accurate enough in making a reconnoissance, or for the mapping of isolated claims; but for accurate work, either transit and tape or stadia, or the plane table and stadia should be used. Another method, the best for most practical purposes where vegetation is not dense, is to use the small plane table and a simple sight alidade (Fig. 16).

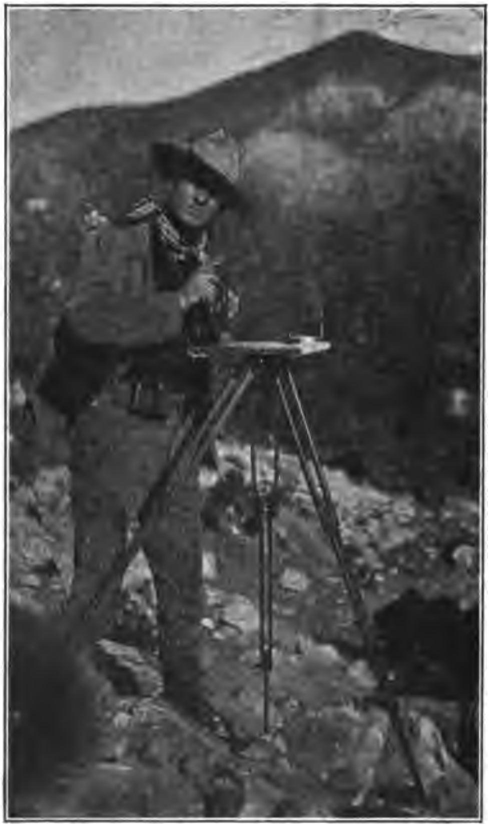

Fig. 16.—Small plane table used in geologic mapping.

The use of the transit may be desirable in wooded country or in rainy weather, when a small note-book is easier to keep dry than a plane table sheet; but it entails the work of plotting in the office from field notes, when field conditions are bound to be hazy. Again, at least two men are required for a transit party. The field work with the transit consists in running traverses to which the main features to be mapped may be tied by offsets or stadia readings.

With the large plane table plotting is done in the field and office work lessened; but for this work also, using the stadia, two men are necessary, and the geologist must do the rodding, which interferes seriously with his work of traversing and observing the formation. It is also difficult for him to do good plotting when he only sees the map occasionally. The method has its chief application when topography and geology are to be mapped simultaneously; in this case it is well to have one rodman to cover the topographic features, leaving the geologist free to follow his own devices until he finds a point that he wants located, when he can hold the rod and signal for a reading.

The method usually adopted for geologic mapping, especially in open areas, is that of the small plane table. The apparatus consists of a board of convenient size (18 in. × 18 in.), of soft wood, on which the map may be mounted with thumb tacks. The ends of this board which are cut across the grain of the wood should be protected by strips of the same wood mitred in and fastened with strong glue. By means of a small brass plate with a threaded socket such a board may be mounted upon an ordinary camera tripod. This plane table is light and portable and big enough to hold the ordinary working sheet.

The geologist's compass, Fig. 17,[1] used in this work has a circle graduated from 0 degrees to 90 degrees in the four quadrants, starting rfom the north and south points. The needle is agate mounted but should not be too sensitive. There is a device for setting the circle to allow for the magnetic declination, so that when the needle reads zero the sides of the compass are in the true meridian. The compass edges may be used as rules and should be graduated to convenient scales, preferably tenths of inches and millimeters. The clinometer needle is so placed that when the compass is held in a vertical plane the needle swings free and points to zero of its scale when the upper side of the case is horizontal. The compass has vanes for accurate sighting, and the case is provided with level tubes by means of which the base may be made horizontal. These levels are used in setting

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[1] Cut furnished by W. & L. E. Gurley.

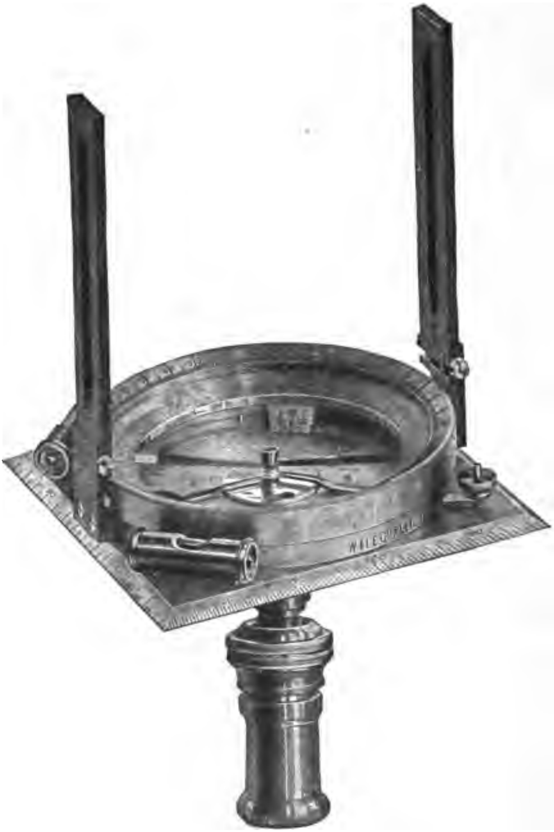


Fig. 17.—Geologists' compass.

up the small table; care should be taken that the needle swings free when the compass is level, if it does not, the cover-glass should be removed, the case cleaned, and the little brass wire on the needle shifted until it is properly balanced. In addition to its use in leveling and orienting the table, and reading directions, the compass also serves as a clinometer in measuring the dip. This use is illustrated diagrammatically in Fig. 18.

The "strike" of a formation is the intersection of its general plane with a horizontal plane. The direction of the strike is

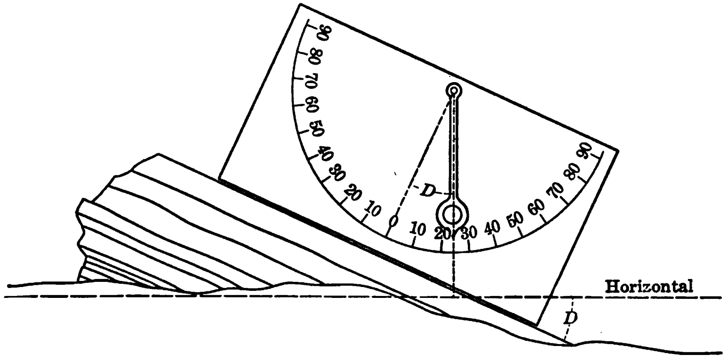


FIG. 18.—Diagrammatic illustration of the use of the clinometer.

read with the compass and is usually given from the north point, as, for instance, N. 30 degrees E. In taking the direction, the edge of the compass may be placed against the actual rock surface, taking care that the instrument is level; or if the formation is somewhat irregular locally, it is well to stand off a little distance and place yourself in the imagined continuation of the plane to be observed, taking a sight to some point on the level of the eye.

The "dip" is the angle (*D*, Fig. 18) which the general plane of a formation makes with the horizontal. It is read at right angles to the strike by placing the edge of the compass held in a vertical plane upon the surface, the dip of which is to be determined; or, the reading may be taken by sighting over the edge of the compass and making it correspond with the edge of the plane observed. Figs. 18 and 19 will perhaps make the foregoing description clearer.

There should be no steel nails or screws in the plane table, and in making the setup care should be taken that the head of a hammer or axe carried in the belt does not deflect the needle. Where there is local attraction due to magnetic ore, slag, scrap iron, or electric wires, the compass cannot be used; if there is much work to be done under such conditions, a sundial compass may be used, or the plane table oriented by a series of trials sighting at known points.

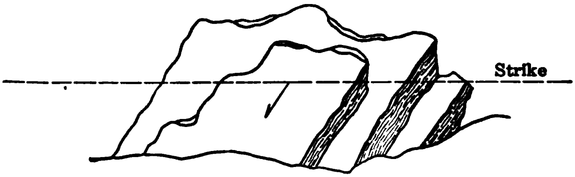


FIG. 19.

The alidade used for this work has a base or double straightedge 12 in. or 14 in. in length, graduated to tenths of inches on one side and to millimeters on the other. The line of sight parallel to the edges of the base is made by two sight vanes 6 in. high, which fold down to the base for convenience in carrying.

The most common method of locating a point on the map is to set up the table, level and orient it by means of the compass, making the true north line of the map correspond with the meridian as indicated by the compass. The edge of the alidade is then placed upon a known point on the map and the point itself (usually a flag, claim monument, or building corner), is sighted. A line is then drawn along the straightedge of the alidade; this is repeated at least twice and the intersection of the various lines is taken as the location of the new point on the map. This is called "making a three pointer." A full discussion of this and other methods of plane table location will be found on pages 4 and 30.

The note-book should be of convenient pocket size and of the loose leaf type, though ring binders are not desirable for field use. A cover with eyelets for the passage of binding cords is more satisfactory. Cross-section paper is very convenient for sketching and plotting to scale.

Hard pencils, 6H to 8H, are best since they do not smudge the map. A sand-paper strip fastened to the under side of the plane table or in the note-book is very handy for giving the fine point required in detailed sketching. Colored pencils are often carried in the field and the different areas are colored as the work proceeds. A small protractor is used in plotting on the map though the compass may be used in the field. The edges of the alidade serve as scales, or if the divisions are not suitable flat wooden scales may be used.

The geologist should always have with him his lens (the Bausch and Lomb Aplanatic Triplet, 3/4 in., is a good one) which may be carried with a soft eraser on a cord or chain; a knife with a magnetized blade, a geological hammer, a specimen sack, and labels complete the outfit.

As to clothes, much will depend on the climate; light kahki is very good for work in hot climates, corduroy more serviceable in the cooler countries where there is more vegetation. Shoes should be heavy and hobnailed, but not waterproofed, unless the climate is very wet. A good substitute for the ordinary hobnail is a small wood screw which may be put in in the field and will not come out. A shooting vest with large pockets is convenient for carrying note-books, and specimens, etc.

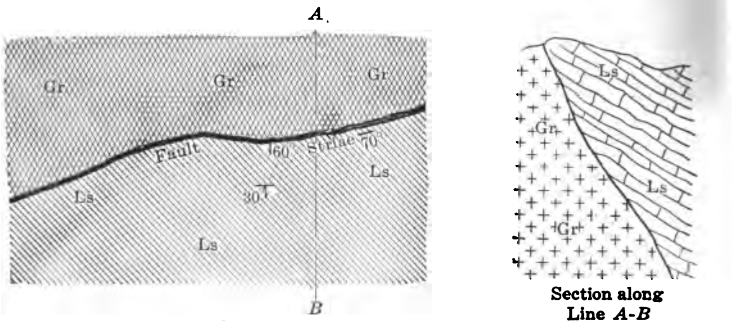
Geological Mapping in the Field.—The first step in examining an area is to make a general reconnoissance. This gives an idea of the formations and the problems to be encountered; it is well to collect specimens of questionable or unfamiliar rocks at this stage of the work, for comparison and to furnish thin sections for microscopic study. If the area is large this trip will give ideas as to the location of roads, trails, water and camping places, which will be of assistance in planning the work. The information so obtained should also serve as the basis for estimates of the probable time and cost of the undertaking.

Detailed Field Work.—For purposes of description observations in the field may be regarded as falling into two broad classes: Those which have to do with the tracing of boundaries, the determination of the relations between formations, and the structural features of the area as a whole, may be taken as one group under the title of

General Geology

The boundary or line of division between two formations exists either as the rocks were originally formed, or is the result of faulting, or possibly metamorphism, at some subsequent period.

The fault boundary, Fig. 20, is the simplest type since it is usually a relatively straight line or has a fairly regular curve; sometimes, however, faults are quite erratic and must be carefully followed. Boundaries between two conformable sedimentary formations, Fig. 21, or volcanic flows, are usually easy to follow unless made very irregular in outcrop by erosion. This is usually the case when the beds are flat-dipping (Fig. 22). A discussion of the effects of erosion and faulting upon outcrops



Fault Boundary - Plan.
Gr = Granite. Ls = Limestone.

Section along Line *A-B*

FIG. 20.—Example of a relatively simple boundary between an igneous and a sedimentary rock, where the limestone has been "down thrown" by faulting against granite.

is hardly within the scope of such a book; references covering the subject are given below.[1]

In mapping an easily followed boundary the plane table need not be set up so frequently and often much sketching may be done by the topography if it has been accurately mapped. It is always desirable to have dips along a boundary but they are not always obtainable. When a boundary comes on a hillside and is badly obscured by débris, the exact location becomes an impossibility; in such a case it is not necessary to be too painstaking in the setups, fragments of the lower formation may be followed up hill and the highest points at which they are found will determine the approximate location of the boundary. Sometimes a noticeable feature of the topography such as an escarpment, or a change in slope, will give a clue as to where to look for a covered boundary, but this cannot always be relied upon.

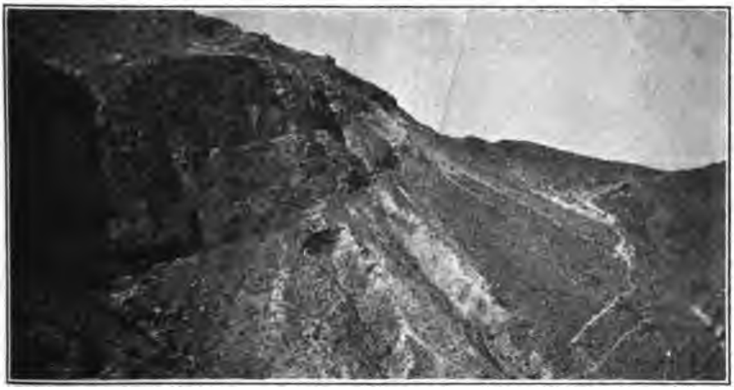


FIG. 21.—Limestone-shale boundary strongly marked by the massive beds of the former standing as a vertical wall above the softer shales. The top of the cliff shows another shale bed.

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[1] "Geology Applied to Mining," J. E. Spurr, pp. 139–142, for migration of outcrop; pp. 149–176, measurement of folds and faults. "Geology," Vol. I, Chamberlain and Salisbury, pp. 500–525.

Complex boundaries are likely to be found when igneous rocks intrude limestones and other sedimentary rocks, or other igneous masses. Arms and dikes go from the main intrusive body for varying distances, Fig. 23, and are often accompanied by alteration and metamorphism which may take place either in the intruded formation or in the intrusive, or both. The commonest examples of this are contacts between limestones and intrusives of the more acid type; varions ferro-magnesian, lime-silicate, and sometimes metallic minerals develop in both the formations until there is every gradation between fresh and completely altered rock of each type. The location of the boundary in such cases becomes a matter of difficulty and it is usually desirable to give the general relations rather than the minute details. This may be accomplished by setting up the table and making short traverses in the vicinity, measuring the distances by pacing. Fig. 24 is an example of such a boundary. The important thing in mapping and studying such a contact is

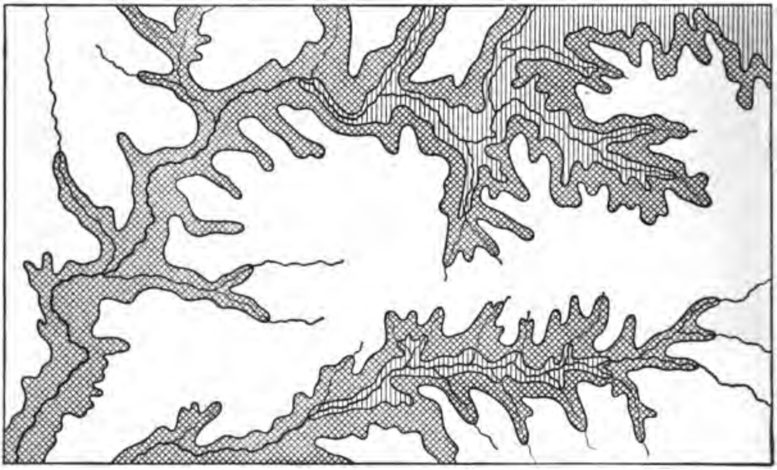
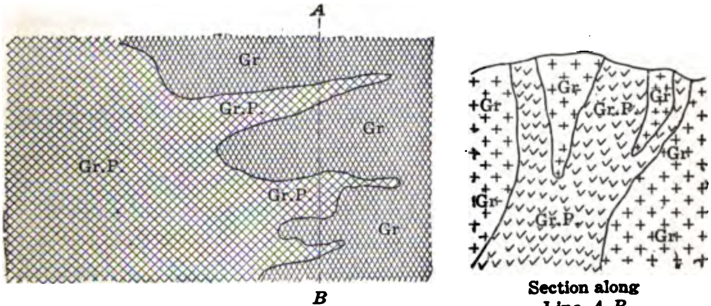


FIG. 22.—Irregular boundaries determined by the stream beds which have been cut in flat bedded formations.

to note the various minerals, the succession in which they occur, and associations which may be of economic value.

It would seem to be a simple matter to tell whether the contact between an igneous and a sedimentary formation is intrusive or a case of the latter simply overlying the former. But in

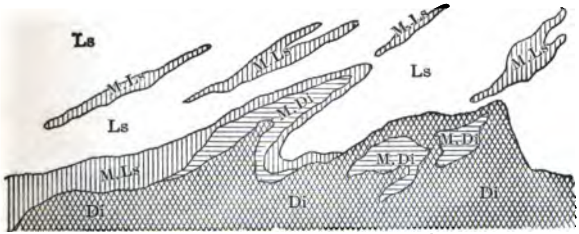


Intrusive Boundary - Plan.

Gr = Granite, Gr.P. = Granite Porphyry.

Section along Line *A-B*

FIG. 23.—Irregular boundaries are usually the rule for intrusive bodies. This is particularly true of the porphyries and finer textured intrusives.



Boundary showing Contact Metamorphism.

Di = Diorite. Ls = Limestone.

M.Di = Metamorphosed Diorite. M.Ls = Metamorphosed Limestone.

FIG. 24.—Contacts of this type offer many interesting problems to geologists, and are usually worthy of the closest mapping and study.

the field relations are obscured in many ways; also small intrusive bodies are hard to find unless they are of a resistant character, or on the other hand, make grooves, or depressions as they weather. This may sometimes be the only evidence of a dike.

A fault boundary is usually characterized by its regularity so that when two formations meet along a relatively straight line, faulting should be expected. Again the absence of dikes along an igneous contact may point to faulting, though not necessarily so.

Work within Areas of the Same Formation.—"Traversing," or "meandering," is simply covering an area in more or less detail by trips along lines which would seem to offer the best chances for additional information. Such trips are made within the boundaries of the same formation for the purpose of observing the various characteristics of the rock and to look for unusual features such as veins and dikes. It is best to work across the strike of the formation, or of the vein system, which is usually mapped by itself and will be taken up later.

In traversing a sedimentary area it is necessary to observe the following things:

Strike and dip of beds.
Character and thickness of beds.
Minerals composing the rock and nature of grains or fragments.
Areas of alteration.
Fossils.
Structural relations as a whole—systems of folds, minor folding, direction and pitch of the axes of folds, relation of folding to faulting, the general distribution of the faults or fractures, etc.
Relations of topography to the geologic features.

Within areas of igneous rocks the geologist should look particularly for the following:

The mineralogical composition of the rock.
The rock texture and variations of it.
Variations in phase of the mass as a whole.
Segregations.
Dip and strike of schistosity or gneissoid structure.

It should be noted whether there is any variation in texture from the margin inward, and whether there is any alteration in certain portions of the rock.

Variations in phase are due to the fact that rock magmas are not homogeneous and that accordingly the chemical and mineralogical composition may vary considerably between different portions of the same mass. In field work it is well to have this always in mind, since it is generally recognized that in many cases the ores are associated with the more acid rocks and the more acid phases of the same rock, so that there may be a decided economic value to such observations.

A segregation is the local occurrence of some mineral or group of minerals in preponderating quantities. Thus there will be portions of the acid rocks that are nearly all quartz; or in the basic types horneblende sometimes develops in quite noticeable masses. Magnetite gathers in this way to such an extent as to form workable ore bodies.

Schistosity results from folding, shearing, and compression, so that by taking strikes and dips of the planes of schistosity some idea may be gained as to the general nature and extent of the forces involved.

In areas of metamorphic rocks the chief point to be determined is the origin of the metamorphosed types. This is quite simple in some cases, such as sandstones altered to quartzites; with recrystallized limestone the determination of age becomes difficult or impossible owing to the destruction of fossils.

With the schists and gneisses the problem of origin becomes difficult, and requires the closest examination in the field, especially if it seems in any way connected with the origin of the ore bodies. It is necessary to examine carefully the distinguishable minerals, both as to their probable original character and the alteration in composition and form. Structural features, such as the strike and dip of schistosity, or gneissoid structure should be carefully noted.

Sometimes silicification and the development of metamorphic minerals are encountered in limestone areas some distance from any igneous contact. Such occurrences should be examined carefully, the minerals noted, and the general distribution of the silicate or altered patches indicated on the map.

Boundaries are shown on the map as fine unbroken lines when their location is certain; broken lines are used when there is doubt as to the accuracy of the representation; dotted lines are used to indicate possibilities. The strike of a formation is shown by a short line plotted accurately or with the direction of strike given in writing; the direction of dip is indicated by a small arrow drawn at right angles to the strike line and with the degree of dip shown near it. Thus the symbol for bedding striking N30°E and dipping 60 degrees to the east would be N30°E—60°. Formations should be distinguished on the map by small symbols such as "Gr" for granite, "Ls" for limestone, and so on. The various areas should also be colored to bring out the relations more graphically. In general, for purposes of uniformity, it is well to follow the usage of the U. S. Geological Survey in the matter of cartographic and geologic symbols; these may be found by reference to almost any of the Survey publications, such as the Professional Papers or Folios.

CHAPTER V

GEOLOGIC MAPPING (Continued)

In Chapter IV I described the methods employed in mapping the general geological features of an area. There remains the discussion of the details which must be observed in the examination of the more important features from an economic standpoint. This mapping of faults, the outcrops of ore bodies, and underground workings requires much more geological knowledge and close attention to detail than the other part of the work; it is not so generally understood and proficiency comes only with practice. The general remarks on field notes, office work, etc., may prove of value to anyone engaging in such work.

In mapping faults enough setups should be made to accurately give the course and to take frequent readings on the dip. The best evidence of faulting to be found in the field, or that which makes the clearest case, is obtained when formations of different type or age are placed in contact as a result of the fault movement. When later formations are laid upon eroded surfaces of older areas the contacts sometimes appear to have been made by faulting, but in most cases the true condition is easily recognized. Straight line boundaries should be examined closely for further evidence of faulting. Further, the geologist should examine marked topographic features, especially those of a more or less straight line character, such as escarpments, and in some cases the water-courses which may have developed along lines of easier erosion made by the crushing of the fault. More closely, he should look for polished or "slickensided" surfaces which usually show the scratching or grooving made by the rock surfaces or fragments as the movements progressed; these marks are the "fault striæ" and indicate the direction of relative displacement. The angle which these striæ make with the horizontal in the case of steeply dipping planes is recorded with a small arrow for direction upon the map. When the fault plane is flat-dipping, the strike of the striæ is given. Brecciated material within the fault walls should be carefully studied, since fragments may have been dragged from some formation not represented on the present surface, and so give an idea as to the amount of movement which has taken place. Again the cementing material and its relation to the fragments may give a clue as to the history of the movement, and may be possible to determine whether it has taken place by successive stages or not.

When a fault or fissure shows mineralization it is a vein, and it becomes necessary to determine whether it is of productive or non-productive type. In many cases this cannot be done until one is familiar with local conditions and has seen portions of the different vein types developed. In the examination of a vein the geologist should note all the recognizable minerals and select specimens for the determination of those which cannot be identified in the field. He should find out as far as possible the order in which they formed—later minerals cut the older ones, or cement fragments of them, or are deposited in the layers of regular cavity filling further from the walls, unless there has been a later reopening of the fissure. Minerals usually occur in certain groups or associations (see p. 130), and this will sometimes help in the recognition of doubtful specimens, or may give an indication as to what may be expected in a certain portion of a vein. It is well to take samples of the vein material while doing the field work to gain some idea of the values and to serve as a basis for recommendation as to systematic prospecting and sampling. Hand specimens of vein material should be taken and kept for reference in the office, especially when the relations between the minerals are not clear to the unaided eye in the field. These may afterward be examined in thin section, or with polished surfaces, with the microscope; in this way otherwise obscure bits of vein history are made clear. (Reference: "The Microscopic Examination of Opaque Minerals," by William Campbell, *Economic Geology,* Vol. I, No. 8. Also "A Microscopic Examination of the Cobalt Nickel Arsenides and Silver Deposits of Temiskaming," by W. Campbell and C. W. Knight in the same number of *Economic Geology*. "On the Microstructure of Nickeliferous Pyrrhotites," same authors, *Economic Geology*, Vol. II, No. 4.)

In the mapping of all productive outcrops, great care should be taken to represent as graphically as possible the exact outline of the outcrop, if necessary, even exaggerating it somewhat in width for the purpose of bringing out relations clearly and indicating the relative importance of the different portions. Variations in width, branches, and intersecting fractures, even if apparently insignificant, should be plotted, since they may bring out causes contributory to the formation of the more important bodies. Alterations of the country rock peculiar to the localities of the ore bodies may be recognized and traced to other bodies which at first glance show no relation to the original set. As an example of this, ore bodies of the "chimney type" have been found to occur along belts connected only by zones of discolored country rock, and developing as a result of intersections with cross leads of apparently unimportant character. By drifting along such a zone as determined by the surface mapping, ore bodies with no outcrop have been located.

The structural features, such as folding, fracturing and shearing, and the character and extent of alteration of the country rock, should be carefully observed in the neighborhood of the ore bodies; any connection between the two may be of importance. For instance, fracturing and shattering along the axis of a fold may produce conditions especially favorable to ore deposition; impermeable beds confine the circulation of transporting solutions, etc.

Field Notes.—An invariable rule for the geological observer should be "Do it now." When he sees anything he should put it down either on his map or in his notes, else he may lose it, for the chances are against returning to a locality once visited, unless there is a strong feeling of having missed something. Then, too, there is always the advantage of having a concrete expression of an idea such as a note or sketch to refresh the memory or to compare with later ideas.

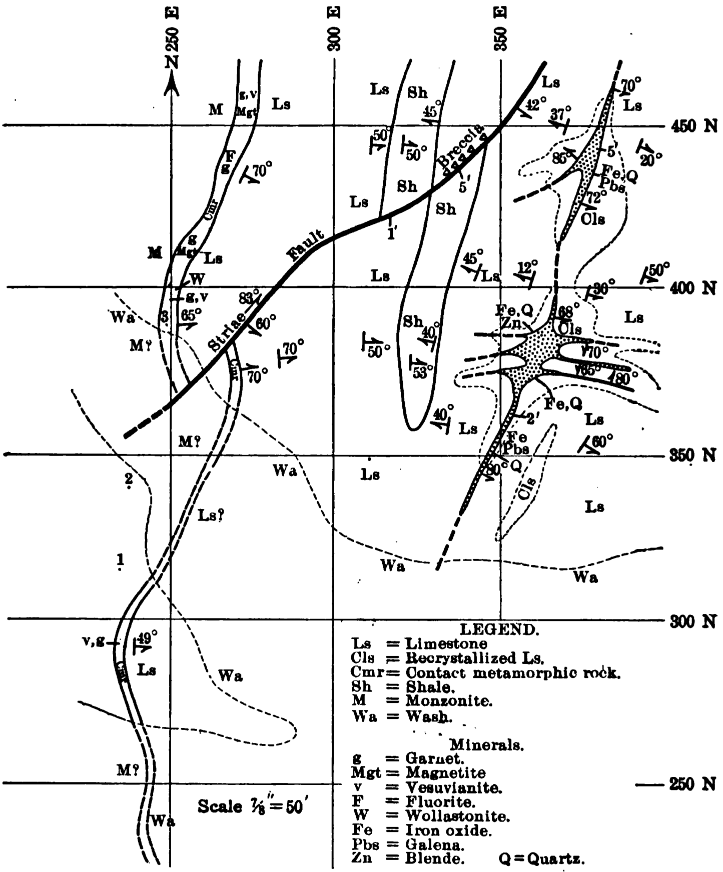
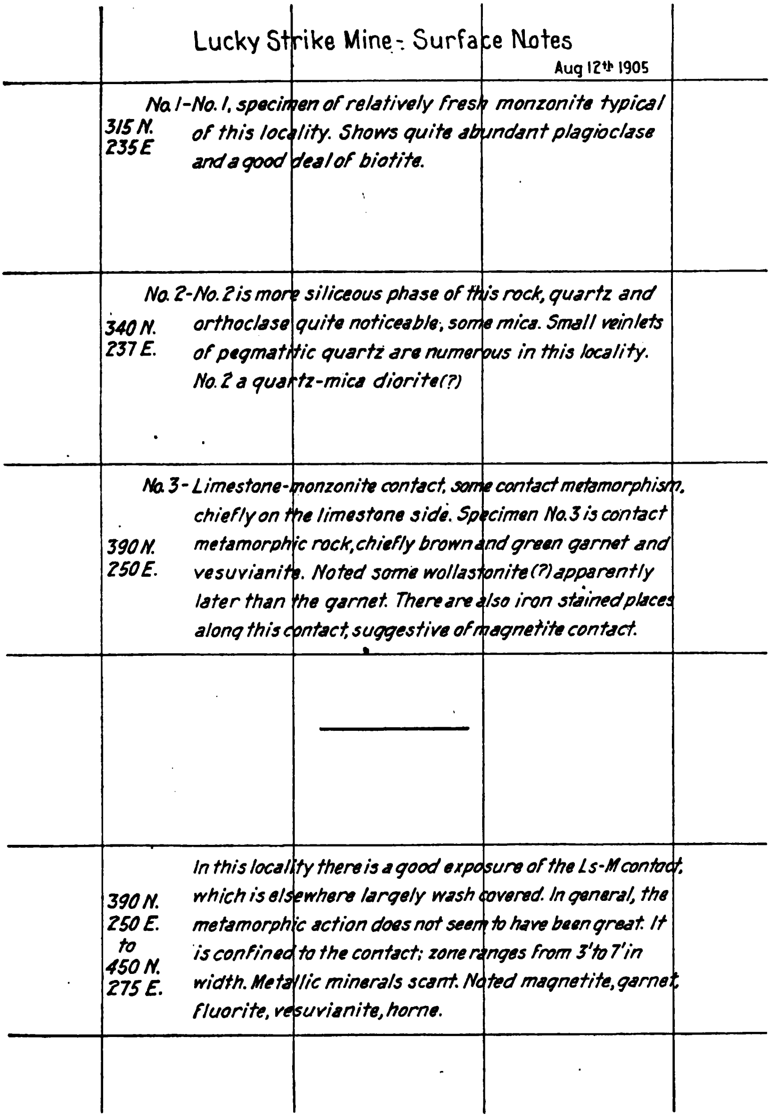


FIG. 25.—This cut shows part of a working sheet, and illustrates the manner of recording as much data as possible on the map. The dotted areas represent outcrops of ore bodies, which are usually inked in red on the field sheets.

Upon the field map (see Fig. 25) should go the data, all of it, that may conveniently appear there, such as notes of the minerals



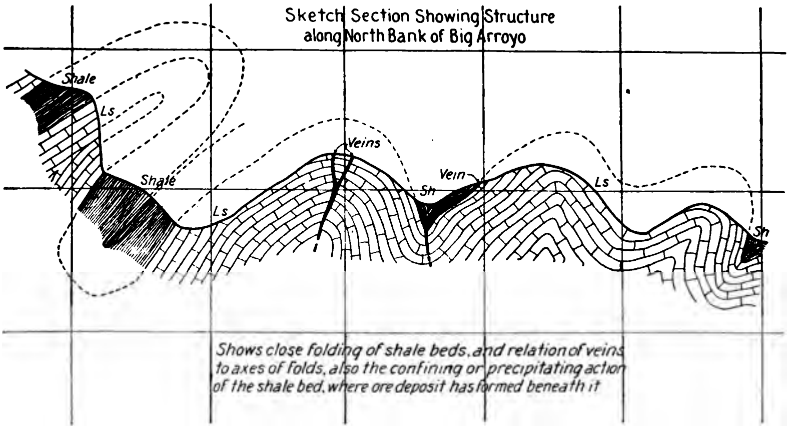
Lucky Strike Mine - Surface Notes
Aug 12th 1905

No. 1 - 315 N. 235 E	No. 1, specimen of relatively fresh monzonite typical of this locality. Shows quite abundant plagioclase and a good deal of biotite.
No. 2 - 340 N. 237 E.	No. 2 is more siliceous phase of this rock, quartz and orthoclase quite noticeable, some mica. Small veinlets of pegmatitic quartz are numerous in this locality. No. 2 a quartz-mica diorite(?)
No. 3 - 390 N. 250 E.	Limestone-monzonite contact, some contact metamorphism, chiefly on the limestone side. Specimen No. 3 is contact metamorphic rock, chiefly brown and green garnet and vesuvianite. Noted some wollastonite(?) apparently later than the garnet. There are also iron stained places along this contact, suggestive of magnetite contact.
390 N. 250 E. to 450 N. 275 E.	In this locality there is a good exposure of the Ls-M contact, which is elsewhere largely wash covered. In general, the metamorphic action does not seem to have been great. It is confined to the contact; zone ranges from 3' to 7' in width. Metallic minerals scant. Noted magnetite, garnet, fluorite, vesuvianite, horne.

FIG. 26.—This shows the method of keeping notes to supplement the mapwork; reference to points on the map is made by giving the coordinate locations.

in veins and contact zones, which may be referred to by abbreviations of their chemical formulas. Vein and fault widths should be noted, and the line followed in traversing should be indicated; vein types should be distinguished by colors. More or less generalized representation is desirable for areas showing alteration or disseminated mineralization.

In addition to the notes upon the map the pocket note-book is used for sketches and descriptions; specimens and samples are described and their numbers, with the map coördinates or locations, are entered on the left margin of the page (see Fig. 26).



Sketch Section Showing Structure along North Bank of Big Arroyo

Shows close folding of shale beds, and relation of veins to axes of folds, also the confining or precipitating action of the shale bed, where ore deposit has formed beneath it

FIG. 27.—This figure is taken from a sketch in a field note book; it is fairly typical of several which were made in studying the structure along this section.

In this book are made sketches of structural features, or sections (Fig. 27); any unusual or interesting thing, such as a case of fault displacement, or a vein formation, is so recorded. Ideas regarding the different problems encountered are jotted down; and every once in a while it is well to go over these ideas and take stock of them, summarizing and arranging for use in further investigation and in the writing of a report.

It is the business of a geologist in investigating an area to see everything that may have a bearing on the problems encountered; to record the things he sees; and finally to interpret correctly the data he has gathered. The success with which he does these things determines his professional ability. It may be necessary in the course of the work, to collect a great many facts that apparently have no bearing on the problem in hand; but in this respect it is much better for a field map to contain too much than too little detail, since it is easy to eliminate, but hard to add, especially when reports are not worked up in the field. The same is true of collections of specimens; superfluous "rocks" may be thrown out the door, but the one that you do not bring in because you are in a hurry, or think you have a duplicate, may necessitate an extra field trip. Consequently, when a new formation or phase is encountered, pick a specimen carefully, with a chip for a thin section, label it and enter the description and number in the note-book. An unlabeled specimen is worse than none at all.

Office Work.—The first thing to do upon coming back from a day in the field is to go over the pencil notes on the map and ink them in, using a fine pen. Boundaries and symbols are put in with black ink and fine lines, faults with heavy black lines, and veins with such colored inks as may be necessary for their distinction. For instance, red is used for productive veins, yellow for possibly productive veins, and brown for barren veins.

The next important thing is to post the work upon a tracing; this gives a duplicate record, insuring against loss, and also makes a convenient copy from which to transfer to the final field map. Posting this tracing should be done as often as convenient, every week at least.

The final field map is simply a print upon which is shown all the work done on the different working sheets. It should be made as legible as possible for the convenience of the men who draft the final maps, and it should be the nearest approach to the map desired as a final result that can be made under field conditions. The color scheme should be carefully worked up and the details exactly as they are to appear on the final. All maps, either field maps, or finals, should have scale, north point, and legend, because one can never tell when someone else will be called upon to decipher his work, and so legibility is always to be desired, unless for some reason the map is so be kept obscure so that the wrong people cannot read it.

The work of transferring from the field sheet to final field copy consists in tracing the various geological features upon tracing cloth or transparent paper, this may conveniently be done upon the tracing above mentioned. A piece of carbon paper, or ordinary writing paper blacked with a soft pencil, is then placed between the tracing and the final field sheet; care must be taken that the coördinates correspond properly. The tracing is then gone over with a sharp hard pencil or wooden point. The lines on the final must now be gone over with inks and the final copy compared square by square with the original to make sure that no details have been missed in the tracing. It may be desirable to make the final map by transferring all the geological data to a good tracing of the topographic sheet; a print is then made and the geology colored in, thus saving the more laborious work of the carbon paper transfer.

Specimens of rocks and vein material are trimmed to a convenient size (3 in. × 2 in. × 1 in., approximately); for marking a small patch of white lead or enamel is painted on a smoother portion of the rock, and this is numbered with black waterproof drawing ink. Corresponding numbers are put on the labels together with the coördinate numbers, and any other data that may be desirable, such as the name of the rock, name of the mine or district, and what the specimen was picked to illustrate, also whether or not a thin section is made (Fig. 28). Finally a list of all specimens, with their coördinate locations, the numbers under which they were collected in the field, and their final or series numbers, must be made and filed with the field notes.

For thin sections chips should be collected in the field at the same time as the hand specimens; if this has not been done they may be selected during the process of trimming, slides may be made in the field without an elaborate outfit. Specimens of opaque minerals may be roughed out on a grindstone, smoothed somewhat with emery or carborundum on glass, polished with finer emery paper, and finally with rouge on felt. The general process will be suggested by Mr. Campbell's paper referred to above. Examination with an ordinary lens will bring out interesting and important relations in many cases.

SPECIMEN LABEL		
Country State Mine Level Exact Location	Location (For Surface Work)	
Number Illustrates Especially	Name { Field Determined	
Collector	Date Note-book Map-book Page	Thin Section No Thin Section Polished Section

FIG. 28.

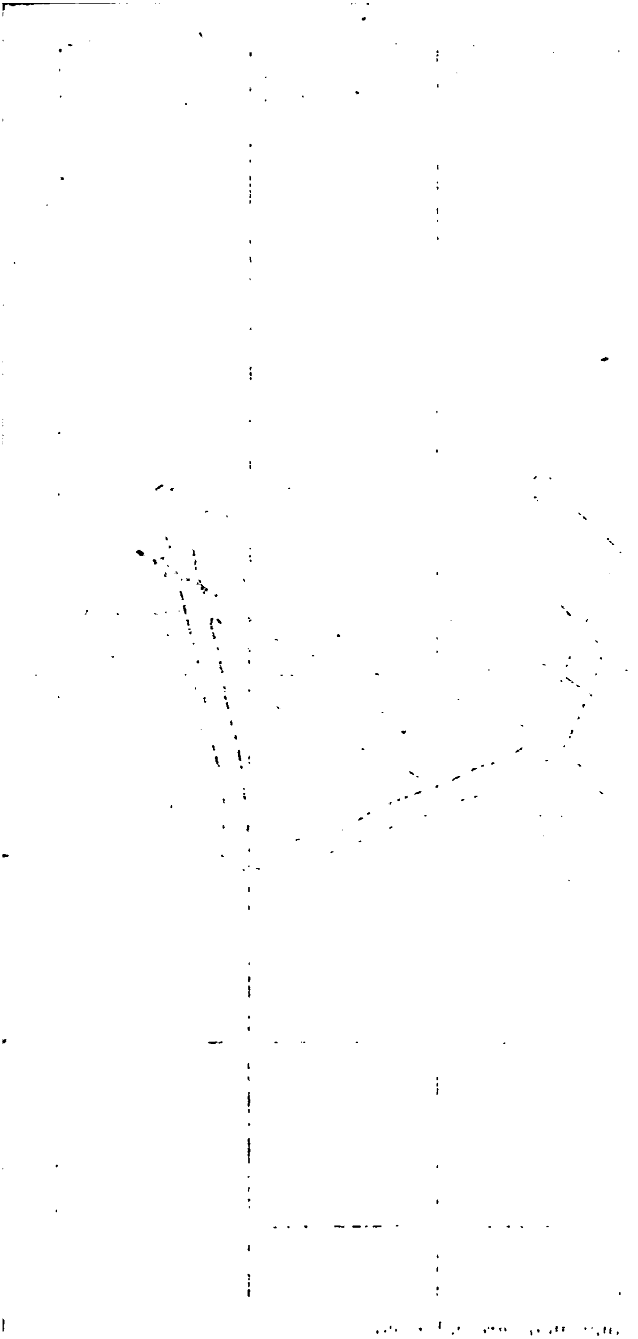
Underground Mapping.—The most important thing in an outfit for underground mapping is a good light. Candles are of little value in draughty workings or in stopes and the grease drops on the note-books and maps. The acetylene lamp is very satisfactory for most work; the light is white, and a small flame is stronger than several candles. The reflector keeps the light out of your eyes and concentrates the illumination on the point under examination. In stopes and bad ground it is of great advantage to see some distance ahead, so that the bright concentrated light is a very desirable thing. Also acetylene burns in air where a candle will not. In choosing the lamp a type especially designed for mine work is best although an ordinary bicycle lamp will do. A glass in front of the burner is not desirable except in strong air currents. The lamp should have handles and a hook by which it can be hung to the clothing when climbing or writing notes. Extra parts, such as carbide reservoir, and burner tips, should always be at hand; a fine wire for cleaning the burner saves much trouble. It is absolutely necessary to clean the lamp upon leaving the mine and it is well to make sure that it is ready to burn before going underground.

A candle or two should always be carried, together with a supply of matches in a waterproof match box.

The note-book for mine mapping is a loose leaf book about 8 in. × 10 in. with sheets of cross-section paper ruled to tenths of inches. An ordinary pocket note-book is carried for sketching, record of specimens, and more extensive notes than can be put on the map-book sheets. Blue prints of the workings in plan and section are desirable for reference, but are not satisfactory for plotting the geology. A clinometer compass, scale, lens, protractor, pencils, eraser, hammer, specimen sack, and labels, complete the outfit.

"Digging clothes" should be chosen with regard to local conditions, and may usually be bought at the local stores. A shooting coat with large pockets is convenient for carrying the map-book and specimens.

Working Maps.—The maps furnished by the engineering office of the mine are the basis of the working maps. They may be altered or amplified in minor details, by compass and tape survey, if necessary. Plans of separate levels are most desirable in preparing the working sheets and in making the final maps they are absolutely necessary. The scale of the map should be chosen with reference to the geological conditions, but the usual working scales of 1 in. = 50 ft., or 1 in. = 100 ft. are satisfactory for most work. The transfer to the underground sheets is made with carbon paper and the outlines are then gone over with ink in light broken lines. As much of the level is shown on each sheet of the note-book as may be leaving ample space for notes. Where the map requires more than one sheet,



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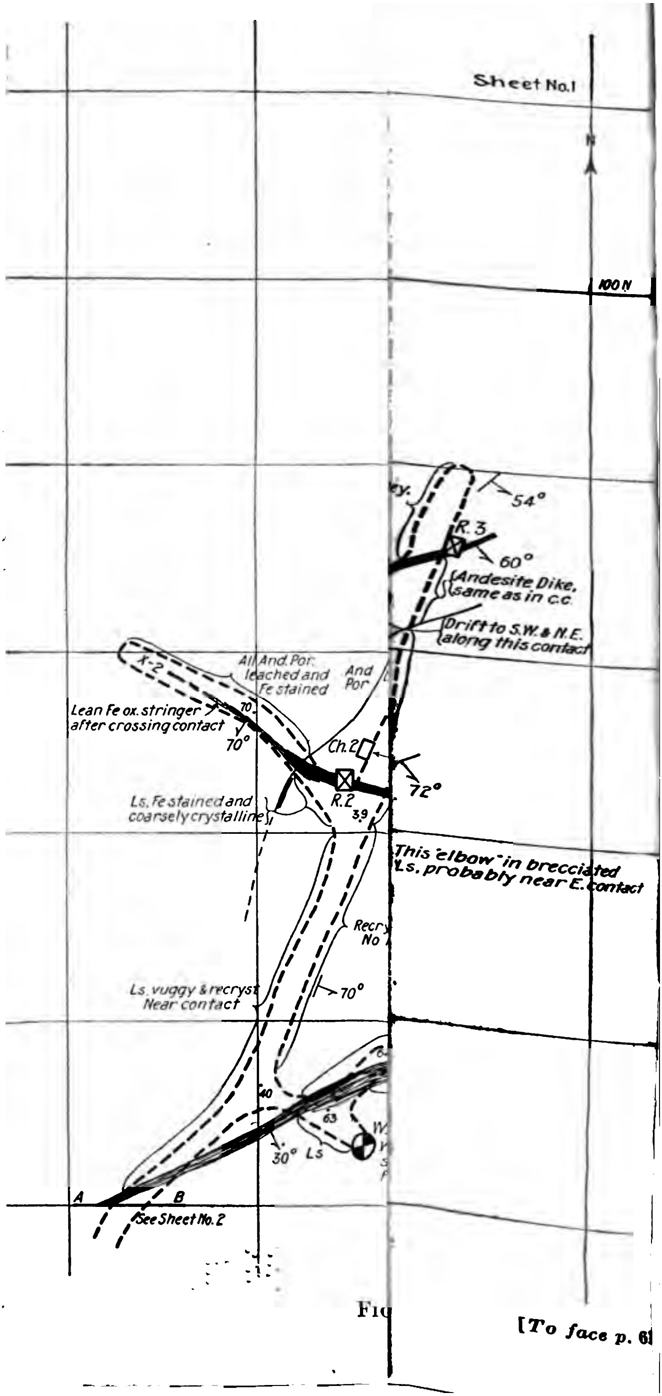
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Ch.2
72°
R.2
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Recr
No
Ls. vuggy & recryst. Near contact
70°
40
63
30°
Ls
A
B
See Sheet No. 2

FI

[To face p. 61

there should be an overlap along some marked line, so that the relation between the various pages will be plain. The north line of the map, the coördinate lines, shafts, raises or winzes, survey points, and names, letters, or numbers referring to them or to cross-cuts, stopes, etc., should all be shown. The greater the number of points by which the geologist can locate himself, the easier and more accurate will be his work. Parts of the workings not on the level should be distinguished by the use of dotted lines. See Fig. 29 for an example of a working map.

Underground Mapping.—The first step in mapping a mine is to make a reconnoissance, preferably in company with someone who knows the workings thoroughly. The general conditions are noted and information is gained as to means of getting about, what parts of the mine are in operation, the signals for the cage, the time of "shooting," etc. For the regular work it is well to have as helper a man who is familiar with the mine, and who can assist in taking sights, measuring, and sampling.

In an unfamiliar mine or district, if the geological conditions are at all complicated, the starting of actual mapping may be attended by considerable confusion of ideas, and relations will seem hopelessly entangled. This in itself is a strong argument for detailed mapping, because by hasty and superficial work absolutely misleading ideas may be obtained. It is well to start cautiously, take a small length of the drift or cross-cut, and go over it carefully, making sure that nothing is missed. As relations develop the work will move more quickly and the true conditions begin to be apparent; when enough work has been done to give a fair grasp of the problems, more speed may be attained. Sometimes it is a good plan to map the country rock and the vein formations separately, so that undivided attention may be given to each group of problems.

The geologist should not leave a locality until convinced that he has reached the proper explanation of any problems encountered; if uncertain, he should bear the place in mind and revisit it as additional facts tend to clarify matters. It is a great mistake to neglect this and be content with the thought that the work done is good enough. No idea should be allowed to crystallize until all the data bearing on the problem is in; it is disastrous to view the facts in the light of a hard-shelled theory.

Locations underground may be made with sufficient accuracy for most practical purposes by pacing distances from known points. To do this the geologist should determine with some care the length of his ordinary step by pacing known distances underground. If there are few known points in the workings, it is well to locate a few by taping to serve as checks on the pacing.

Features to be Mapped.—In general, the remarks which were made upon surface mapping also apply to work underground, and it would be useless to repeat them here in detail; the following paragraphs summarize the points which were so treated and will serve as a working synopsis. Only those points which are peculiar to underground conditions will be taken up more fully.

The geologist locates the boundaries between formations and notes: (1) strike and dip; (2) general character—whether regular or irregular; (3) if between sedimentary formations or flows, whether comformable or unconformable contact; (4) evidences as to faulting, fracture, and alteration; (5) if an igneous rock is encountered, whether or not it is intrusive; also evidences of contact metamorphism and alteration.

Whenever possible, strikes and dips of sedimentary rocks and schistosity should be recorded.

The strike and dip and width to scale of dikes are shown, and in the notes, marginal phases, included fragments, and metamorphism, are described.

In examining faults and fracture zones the following points are observed: (1) strike and dip; (2) evidences of movement, such as slickensided walls, striæ, "gouge," and drag; (3) cross fractures, offsetting of one set by another and anything else that may give an idea as to relative ages of the fracture systems.

Veins: (1) strike and dip; (2) general character of mineralization—whether strong or weak, oxidized or unoxidized vein material; (3) minerals or groups of minerals; (4) relative ages of the minerals; (5) sketches of the formation are made where any of the foregoing points are well illustrated (see Fig. 30).

Other ore bodies: (1) the general strike and dip, in addition to the points mentioned above; (2) the graphic representation of the outline of the ore body with the idea of bringing out the reasons for its occurrence.

The widths of veins, faults, and fractures, should always be noted on the map. Stopes are shown accurately in outline but are distinguished from vein material by cross hatching or some such symbol.

In studying ore bodies in general, the following points should receive a good deal of attention: (1) the character and extent of the alteration of the country rock near the ore body; (2) nature and extent of the replacement of the wall rock by the ore, branches and false walls.

The alteration of the wall rock may be even more important underground than on surface, since there is no superficial weathering to obscure it; in some cases this may be a valuable indicator of the proximity of ore and accordingly it is well to study the question carefully. Endeavor to determine the causes of the changes and be prepared to recognize the characteristic signs wherever encountered.

Replacement[1] of the country rock is a process which plays an important part in the formation of ore bodies in rocks which are soluble in the ore bearing solutions; this is especially the case in limestone, where replacement is likely to take place on such a minute scale as to preserve all the features of the country rock in the ore. When ore and rock are somewhat similar in general appearances, as in the case of smithsonite or "bone carbonate" in a white limestone, it is often hard to distinguish the two without tests, and ore may easily be overlooked.

All branches of veins should be carefully plotted on the map even when apparently insignificant. If the entire drift is

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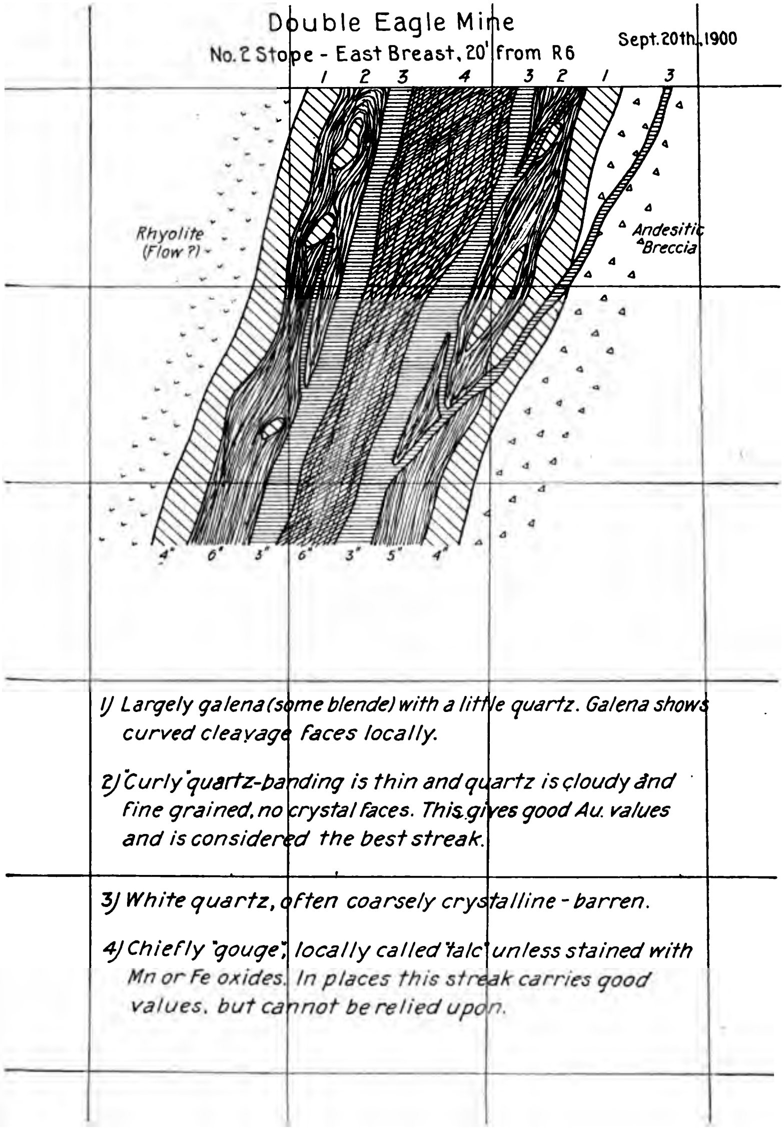
[1] "Replacement Ore Bodies and the Criteria for their Recognition," J. D. Irving, *Economic Geology*, Vol. VI, No. 6.



Double Eagle Mine
No. 2 Stope - East Breast, 20' from R6
Sept. 20th, 1900

1 2 3 4 3 2 1 3
Rhyolite (Flow ?)
Andesitic Breccia
4" 6" 3" 6" 3" 5" 4"

1) Largely galena (some blende) with a little quartz. Galena shows curved cleavage faces locally.

2) "Curly" quartz-banding is thin and quartz is cloudy and fine grained, no crystal faces. This gives good Au. values and is considered the best streak.

3) White quartz, often coarsely crystalline - barren.

4) Chiefly "gouge", locally called "talc" unless stained with Mn or Fe oxides. In places this streak carries good values, but cannot be relied upon.

FIG. 30.—A sketch from a page of underground notes which shows successive stages of vein formation.

in vein material it requires careful work to detect branches, with the result that with further development a horse of country rock or a slickensided fault plane may be taken for the true wall, leaving considerable bodies of ore undiscovered. In a "linked vein" formation where ore bearing solutions have formed parallel leads, connected only by small fractures or not at all, this matter of false walls should be kept in mind and development work so directed as to preclude the chance of missing anything.

CHAPTER VI

GENERAL SUGGESTIONS FOR GEOLOGICAL WORK

Summary of observations for geological mapping:

A. Reconnoissance of the area.
  1. Is the geology simple or complicated?
    a. Do the different formations cover large or small areas?
    b. Is it easy to distinguish between them?
    c. Are the boundaries easy to find and follow?
  2. What are the probable rock types and their relations?
    a. Are rocks of igneous or sedimentary origin or both?
    b. Are contacts conformable or unconformable?
    c. In case of intrusive bodies are there large dikes or masses and few in number, or are they small and widely distributed through the intruded formations?
    d. Are the rocks much altered?
    e. Is metamorphism a prominent feature?
  3. Collect specimens of the different formations, giving locations as closely as possible.
  4. Note roads, trails, water, and possible camping places.

B. Geological mapping—general.
  1. Locate boundaries between formations.
    a. Simple boundaries.
      (1) Take strike and dip.
      (2) Does boundary indicate conformable or unconformable contact?
      (3) Are there evidences of faulting?
    b. Obscure boundaries.
      (1) Look for fragmental traces of the formations.
      (2) Work up hill and locate the highest points at which fragments of the lower formation appear.

- (3) Note whether scarps or changes of slope are connected with the boundary.
- c. Complicated boundaries.
    - (1) Intrusive boundaries.
        - (a) Map carefully dikes and arms.
        - (b) Note alteration and metamorphism in the neighborhood of the boundary.
        - (c) Note variations in texture of the igneous rock in approaching the boundary.
    - (2) Boundaries showing contact metamorphism.
        - (a) Map the general relations of the metamorphic patches.
        - (b) Note the metamorphic minerals and their succession.
        - (c) Note presence and associations of ore minerals.

2. Work within the boundaries of a formation—traversing.
    - a. In areas of sedimentary rocks note:
        - (1) Strike and dip of beds.
        - (2) Color, thickness, and general character of beds.
        - (3) Minerals composing the rock; nature of the grains or fragments (angular or rounded); cementing material. In conglomerates look for recognizable fragments of earlier formations.
        - (4) Presence of fossils.
        - (5) Areas of alteration.
        - (6) Areas of metamorphism.
        - (7) Systems of folds—minor folding-direction and pitch of axes of folds—relations of folding to faulting.
    - b. In areas of igneous rocks note:
        - (1) Rock texture and variations of texture.
        - (2) Variations of composition.
        - (3) Segregations.
        - (4) Inclusions of other rocks.

            - (5) Dip and strike of schistosity or gneissoid structure.
            - (6) Flow structure.
        - c. In areas of metamorphosed rocks note:
            - (1) Is rock of sedimentary origin?
                - (a) Does it show traces of bedding? Are the gneissoid laminæ continuous, suggestive of sheared beds?
                - (b) Are the grains rounded or angular in outline? What are their relative sizes?
                - (c) Are the minerals such as to suggest erosion or metamorphic processes?
            - (2) Is the rock of igneous origin?
                - (a) Are the minerals typical of igneous rocks?
                - (b) Are the gneissoid laminæ non-continuous, suggestive of sheared minerals?
            - (3) Are the changes the result of dynamic action or chemical action, or both?
                - (a) Is the rock texture suggestive of folding and shearing?
                - (b) Does it suggest an impregnation and metamorphism by replacement process, due to action of solutions?
            - (4) Is the rock widely different in structure and composition from the original type?

- C. Geological mapping—detailed work.
    - 1. Faults.
        - a. Strike and dip.
        - b. Evidences of movement—slickensides, striæ (their direction and dip), "gouge," and "drag."
        - c. Cross fracturing.
    - 2. Veins and other ore bodies.
        - a. Strike and dip.
        - b. General character of mineralization.
            - (1) Strong or weak.

    (2) Oxidized or unoxidized vein material.
- c. Minerals and groups of minerals.
- d. Relative ages of minerals.
- e. Represent exact outline of ore body as far as possible.
- f. Note occurrence of branches or false walls.
- g. Note character and extent of alteration of country rock near the ore body.
- h. Nature and extent of replacement of the wall rock by the ore.

CRITERIA OF RELATIVE AGE

1. Older rocks are more likely to have been deformed and metamorphosed, and therefore are harder to recognize.

2. Older formations are normally at the base of series of sediments and flows.

3. Older formations are represented by fragments in later formations.

4. Younger formations fill in erosion irregularities, and fractures, fault planes, or caves in older formations.

5. Younger formations cut the older ones as dikes, and include fragments of them.

The tabulations given above summarize the chief points which are of importance in making a geological examination of a metalliferous deposit, not placer ground. Other comprehensive "schedules" applying to placers, iron ores, coal and oil, and other economic materials, may be found in C. W. Hayes' "Handbook for Field Geologists."

To complete the discussion of geological field work it is necessary to add some description of the general methods of procedure, taking up more fully those points which have been only mentioned, and going somewhat into the question of how to look for things in the field.

If an area is quite large and there are to be several men engaged in the work, it is necessary to plan the method of going at it with some care in order to get the best results; such a working plan will, of course, be subjected to revision as the work progresses. It is axiomatic that those of the party who are more experienced or who possess the keenest powers of detailed observation should be assigned to the more complicated regions and the localities of the ore bodies. With two or three geologists employed it is easy to compare results and harmonize the work, but with an increase of force it is best to have one man, presumably the head of the party, work with each of the others in turn; in this way he keeps all the problems in mind, can correlate the facts to some extent, and suggest to the others the best methods of procedure. When the work is finished, he has a grasp of the entire situation and is prepared to write a report based upon the reports submitted by his assistants.

When the geological formations have a general definite strike, it is well to divide the area into strips at right angles to the strike, thus giving the different men chances to work at all the problems which arise, and so have the benefit of their various ideas. The men should join their areas in the field, preferably by working along the junction lines together; if this cannot be done, boundaries may be transferred from one working sheet to another so that each man may pick up the work that the other has done and leave no loose ends.

In dividing an area to be mapped, topographic conditions should be considered, as well as geological features. A man working in a very rugged locality would not be expected to cover as much of the map as in a smoother area. Again. the working rates of individuals vary considerably in this as in any other work, and while a certain spirit of rivalry is desirable, it should not lead to the doing of careless work for the sake of speed. It is a good thing to actually measure the area covered each day or each week, so as to have an idea of the working rate as a basis for future planning.

The question of how to look for things in the field is one which it is very difficult to treat in a satisfactory manner, since any particular method may not appeal to everyone. In following boundaries which are not clear, for instance, some men prefer to work along the line step by step, making sure of each portion as they go; others would rather "zig zag" across the line looking for unusual conditions which may lead to the discovery of irregularities. The choice, of course, depends on the observer and the field conditions. Some boundaries may be difficult to locate when you are close to them, and yet may show up very strikingly from a little distance. In regions where erosion has brought out the different forms sharply such general impressions may be of great value, since it is difficult, if not impossible, to reach the boundary in many instances. Under such conditions it is a good plan for two men to work together, one doing the general mapping at a distance and the other verifying results at close range; where there are deep, narrow valleys, this is especially effective because each man can do his own detailed work and make long range observations for the other. Under exceptional conditions they may discuss matters at easy shouting distance, where it would take an hour or two, perhaps, to climb down and then up the other side of the gorge.

Upon going into the field in a region which is entirely new the geologist may be much perplexed by the things he sees. Weathered rocks do not look at all like the fresh types, especially in the case of the basic rocks and it is necessary to look carefully for the signs from which to deduce the original character. These may be the more resistant minerals, or the outlines left by crystals which have disappeared, or the nature of the residual products themselves. The following is a tabulation of the alterations commonly encountered in the main rock groups:

Original Type	Alteration Products
Rhyolite-granite group.	Clays and kaolin, with quartz grains from the coarser textured types, usually light colored masses.
Trachyte-syenite group.	Similar to above except that quartz will not be found.
Dacite-quartz diorite group.	Simila · to first and following group; more secondary calcite may be found than in alterations of the first group.

Orignal Type	Alteration Products
Andesite-diorite group.	Casts of mica and hornblende in coarser textures; material may be dark gray to dark green, with red or purplish tinges.
Basalt-diab se-gabbro group.	Serpentine, chlorite, kaolin; colors prevailingly green, rocks often called greenstones.

In addition to the examination of the altered rock, the geologist will be on the watch for less altered types of the same formation, and if he succeeds in finding them will compare the unaltered and altered types and note the nature of the changes. It should be remembered that alteration is characteristic not only of rocks which have been subjected to weathering, but also of those which have been exposed to the action of underground waters. Sometimes the change is purely alteration or the leaching and removal of certain constituents; sometimes a more complicated process is involved.

The term "metamorphism" implies, from its derivation, the idea of a change in the original rock either of the form of its constituents, the chemical composition, or both. It at once becomes apparent that we are dealing with something more difficult to understand than alteration. Very long and learned treatises have been written on the subject and one should be in some measure familiar with these discussions. Then, too, the changes are such that they often cannot be determined without the use of the microscope, sometimes not at all. But in the field we must do as much as we can to clear up the question of origin. Near the boundaries in the case of "contact metamorphism" we must note the general relations to the igneous mass, and map carefully the bodies of different contact minerals, noting their age relations. Areas of unchanged rock should be watched for closely, and the metamorphosed areas traced to unchanged portions of the formation. In the case of the schists and gneisses we can tabulate the recognizable minerals and compare them with those which are known to result from changes of the various rock types. It is also necessary to be on the lookout for any structural or textural features that may have been preserved from the original rock. Below is a tabulation of the metamorphic forms resulting from the commoner types:

Original Rock	Metamorphosed Rock
Rhyolite.	Rhyolite schist; with alteration, sericite schist.
Granite.	Granite gneiss.
Trachyte-syenite group.	Schists and gneisses analogous to above mentioned types.
Dacite-quartz diorite group.	
Andesite.	Andesite schist.
Diorite.	Diorite gneiss, hornblende and amphibolite schists.
Basalt.	Hornblende schist, chlorite, "green schist."
Gabbro, pyroxenite, peridotite.	Corresponding gneisses, amphibolites, and hornblende schists.
Conglomerate.	Conglomerate gneiss.
Sandstone.	Quartzite.
Argillaceous sandstone, shale, etc.	Quartz, mica, and hornblende schists; metadiabases and metadiorites.
Limestone.	Crystalline limestone, dolomite.

Shales and limestones also give various types of contact metamorphic rocks near igneous intrusions; this subject is taken up in more detail in a later chapter (see p. 144). One of the commonest results of such metamorphism is silicification; when a rock has been greatly silicified, it is difficult to tell whether it was originally of igneous or sedimentary origin; thus, a silicified limestone may greatly resemble a silicified porphyry. Almost invariably, however, silicified igneous rocks have a peculiar appearance, due either to the remains of the larger crystals or to some effect which they produced on the replacing material. This may be just a suggestion of a mottled appearance which will be increased by wetting the surface. Usually when there is a suspicion that a rock is of igneous origin it turns out to be so.

If there is doubt as to the original character of a rock great care should be taken in looking for traces of bedding planes as proof of sedimentary origin; also when the bedding is not distinct as many dips as possible should be obtained. Ideas as to the bedding and dip may sometimes be gained from some little distance away, the opposite slope of a valley for instance. Even if actual dips cannot be taken with certainty, the general impression of the structure should be recorded upon the map by dip symbols. Limestones which appear massive at first glance may show traces of bedding in lines of peculiar "suture joining."

In working out structural relations, the long distance method is usually most satisfactory, especially when it is based upon dips properly taken. All such ideas as to structure should be carefully recorded in the note-book as described on page 56.

When starting the work within the boundaries of an igneous area the observer may at first be confused by the variations in composition and texture. In this case it is well to study the various phases carefully, representing the more important variations on the map until certain that they really are parts of the same mass. If then there is no relation of economic importance indicated, in future, mapping differentiation may be neglected.

The question of rock classification in the field is rather a difficult one; in fact any rock classification not based upon chemical analysis, especially in the case of igneous rocks, is rather indefinite from the very nature of the things with which it has to deal. The general lines along which to follow are discussed later (Chapter XII); the point to be emphasized here is that the naming of a rock in the field is of secondary importance. The principal things are to recognize the field relations, identify the rock itself in different parts of the area, and be able to tell it in the altered or metamorphosed forms which will probably be encountered in mineralized localities. At any rate, it is probable that a provisional determination can be made in the field to be checked later by microscopic examination, and that this will be sufficient for all practical purposes.

The following discussion will perhaps seem a little extreme to a good many readers, even those who were willing to read the paragraphs on how to look for things in the field. The region of the mind and its processes is still such a frontier that there is some hesitancy about venturing any remarks, whatever.

In the first place, however, what are the requisites necessary to the making of a good geologist? It is almost axiomatic that one should be fond of life in the open, a life that may prove rather strenuous at times; one must be indifferent to physical discomforts, and not overly dependent upon the amusements and attractions which form a large part of life in the centers of civilization.

But perhaps the chief requisite for a successful geologist is that he have a mind keen and careful in the observation of details. If a man's mind works too readily toward generalizations, if it tires as a result of concentration, or if it is incapable of concentration, he should not take up those branches of geology which have to do with the economic application of the science. In watching a good geologist at work, the average person is inclined to ask, "Why does he putter about over one thing so long?" The point is that the "one thing" may to the geologist mean a variety of things, each one of which must be thought of and noted. Again, a restless mind, even if of the inquiring type, may tire when half through an investigation, and slur the rest of it. The ability to see details is at a great premium in economic work. The mind should also be of the methodical, systematic type, which will insure the taking of notes in a thorough way and keeping them in a form easily available for future reference.

Almost on a par with the ability to do detailed work is a second requisite which seems almost contradictory to the first; this is the faculty of thinking logically and grasping situations as a whole in all their possibilities. It would seem that a mind fitted for detailed thinking and observation would not be likely to possess this qualification also. Possibly the rareness of the combination accounts for the rarity of geologists of the "first magnitude." It may be that some mental process is here involved which we do not yet understand. Suppose, for example, that the work of observation and record, which is preeminently the province of the conscious mind, must be followed by the arrangement of the facts, their comprehension as a whole, and their "crystallization" into a series of new ideas, which processes may be the work of the subconscious faculties. This would appear to coincide with the theory of genius, and at any rate it is an interesting speculation.

More especially so since it brings us face to face with the question of how to think. In the first place one should not try to do too much abstract thinking in the field or when working up the maps; under those conditions there are many things to interfere with concentrated mental effort. It is best to confine the attention to the work of observation, making sure that no details are missed and avoiding the formation of theories without sufficient data. This is the period for the collection of evidence from which the conception of the geological conditions and possibilities is to be elaborated. We have all had the experience of working over a difficult mathematical problem, at last giving it up in disgust to think of something else or to take a night's rest. Upon taking up the problem again the solution has seemed perfectly clear, or possibly it flashes upon us fully outlined before we consciously turn our attention to it again. It would seem that this process might be deliberately employed in the treatment of geological problems; given the data the mind should be allowed a period of uninterrupted meditation to digest and assimilate the facts. This may be done while walking over the area or sitting in quarters, so long as there is nothing to distract the attention from the matter in hand. It is certain that ideas develope in this way with greater clearness and coherency than when one works under "forced draft."

In both field and office work it should be remembered that there is a limit beyond which it does not pay to go. One hears of men who put in long days of twelve to fourteen working hours and, though the capacity of different men for concentrated physical or mental effort varies greatly, it would seem that this may be exceeding proper bounds. A man who would never dream of working an engine or motor under such conditions never plots his own curve of efficiency. When the results obtained are very small for the last three hours of a working day as against the first three, it becomes a question whether it is really worth while to put in a long day. When you find in the field that your powers of observation are becoming impaired, or in the work of summing up that you are "thinking in circles," it is best to stop, because the results will not be satisfactory and you run the risk of making serious errors. Overtime work is necessary under some circumstances, but the overtime should not be put in by the man who takes the responsibility for the final report.

CHAPTER VII

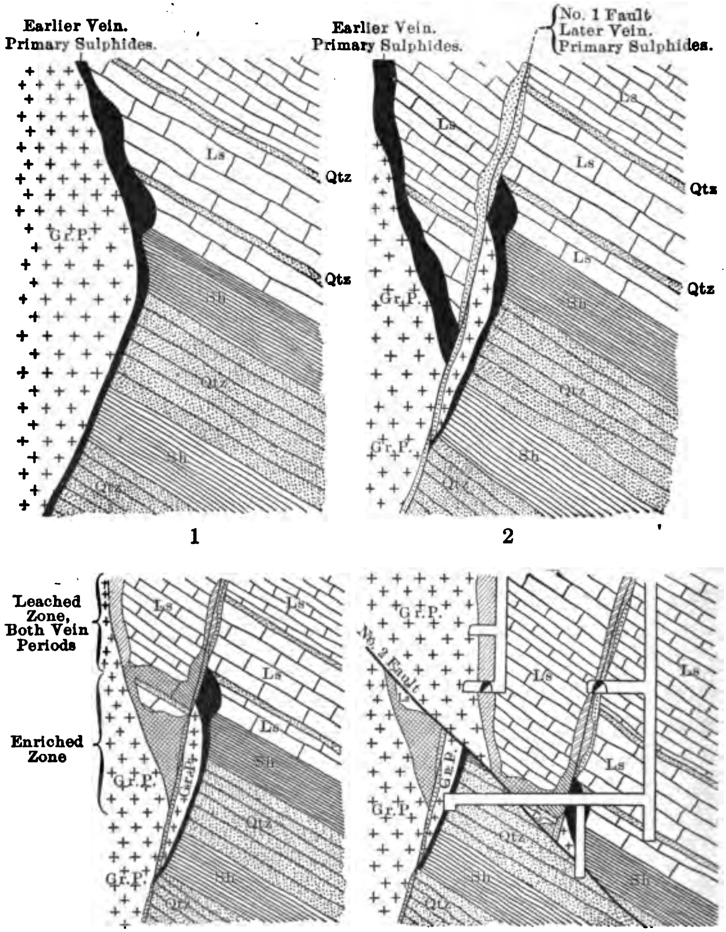
THE INTERPRETATION OF GEOLOGICAL DATA

The interesting part of a geological examination comes when most of the field work has been completed and the geologist is occupied in drawing conclusions and making recommendations. Upon starting work in a new district many things are not clear and one is at a decided disadvantage in discussing matters with men who are familiar with local conditions. But as the work progresses and one's grasp of the subject improves there come a feeling of satisfaction and a desire to have all the facts in shape for demonstration. When one gathers his maps and notes for this final study of the problem, and as his ideas shape themselves into a logical outline of the problem, there is experienced something of the excitement of the explorer who sights new shores, or of the prospector who is driving a tunnel to cut the vein. On the whole, one is amply repaid for the long days spent in the hot sun or in crawling through old workings under ground. In the following pages an attempt will be made to indicate along general lines the methods by which geological conclusions are reached.

Given maps of the surface of an area, maps of the underground workings, and the accompanying sets of field notes, it next becomes necessary to correlate and explain the facts so recorded. It is the end of such work to gain as clear a conception as possible of the true geological relations, the processes from which they resulted, and the practical bearing of these things upon the mining work. There is always difficulty in grasping relations of a complicated nature, and graphic or diagrammatic aids are resorted to whenever possible; they are especially valuable when thinking in three dimensions is to be done. Accordingly, in addition to the plans it is necessary to construct sections and projections which show the geological relations in a vertical plane. These are taken either east and west "looking north" or north and south looking east; that is, for a section having a general east and west direction the left hand side as you look at it represents the west end of the line along which the section is taken; similarly with a section having a north and south trend, the left side of the section represents the north end of the line.

The lines of the sections are ruled on the surface map as nearly at right angles to the strike of the formations as may be; the ends of the section are clearly indicated on the map. The horizontal and vertical scales should be the same as the scale of the map for the quickest work. The most convenient method of constructing the section is as follows: cross-section paper is used and on it are marked the lines of elevation which correspond to the chief contour numbers on the map; the bottom of the section sheet is then made to coincide with the line ruled on the map along which a straightedge is laid. Lines are now drawn at right angles to the straightedge from the points where the section line cuts the contour lines or any other line the position of which is required on the section. Where such a vertical from a contour cuts the line of elevation on the section corresponding to the elevation of the contour, we have a point representing the surface of the ground and a series of such points connected give the required profile. The method is much more rapid than plotting with scale or dividers, and it applies to the location of any point which is to be transferred from the map to a section. Drill holes and mine workings on or near the line of the section are plotted upon it. Fig. 7 illustrates most of the points above mentioned.

One set of sections through the mine workings is made with reference to the lines along which most information is available; others are taken where the conditions are particularly complicated. Thus, one works from the easier to the harder problems, and by studying them together arrives at solutions that may have seemed impossible at the start. If the geology is very complex it may be advisable to make sections representing the successive stages of the problem. Such a case may be found in Monograph 31 of the U. S. Geological Survey, pp. 181–188, in



1 2

3 4

FIG. 31.—A series of diagrams of this type may be very useful in illustrating the history of a deposit. In this case sketch (1) shows the probable condition after the intrusion of granite porphyry, at the end of the first period of mineralization. In (2) there is shown No. 1 fault and the later vein which it produced; (3) gives an idea as to the effects of oxidation and enrichment, while (4) based on present conditions indicates interesting possibilities.

connection with the description of the Smuggler Mine. Fig. 31 shows a case where this method was used with advantage.

Models of mine workings showing the geology are often valuable and instructive; levels are drawn upon panes of glass or celluloid sheets which are put in their proper positions in a frame; shafts, raises, etc., are shown on glass sections placed between the level panes. As a rule, however, models are unnecessary where separate maps of the various levels and good sections have been made.

Assay plans of the mine workings are very valuable; all assays should be plotted on the maps giving the number, the sample location, its width, whether the cut is made horizontally or vertically, and the assay value of the ore. Fig. 32 is a portion of an assay plan. In the case of deposits which are not very wide and quite regular the assays may conveniently be shown on the section or projection. Where there is so much information available that it cannot be studied conveniently in detail some graphic method of showing the values is very desirable. This may be done by using colors to represent certain ranges of value; when such a scheme has been worked out, it will show at a glance the general distribution of the richer ores and the way in which the values vary.

When sections and assay plans have been completed the most interesting part of the work begins. This consists in the comparison of the different maps, the correlation of the facts so obtained, and the drawing of inferences from them.

The study of the general sections should bring out the structural features of the area as a whole and their relations.

When all the available data have been plotted on the sections the next step is to indicate the relation between the different formations and endeavor to imagine and represent what has taken place in regions where no data are available. In the first place, if we are dealing with an area of folded sedimentary rocks we must show the relations between portions of the same bed occurring in different parts of the section. When there is some easily recognizable member it becomes relatively easy to correlate

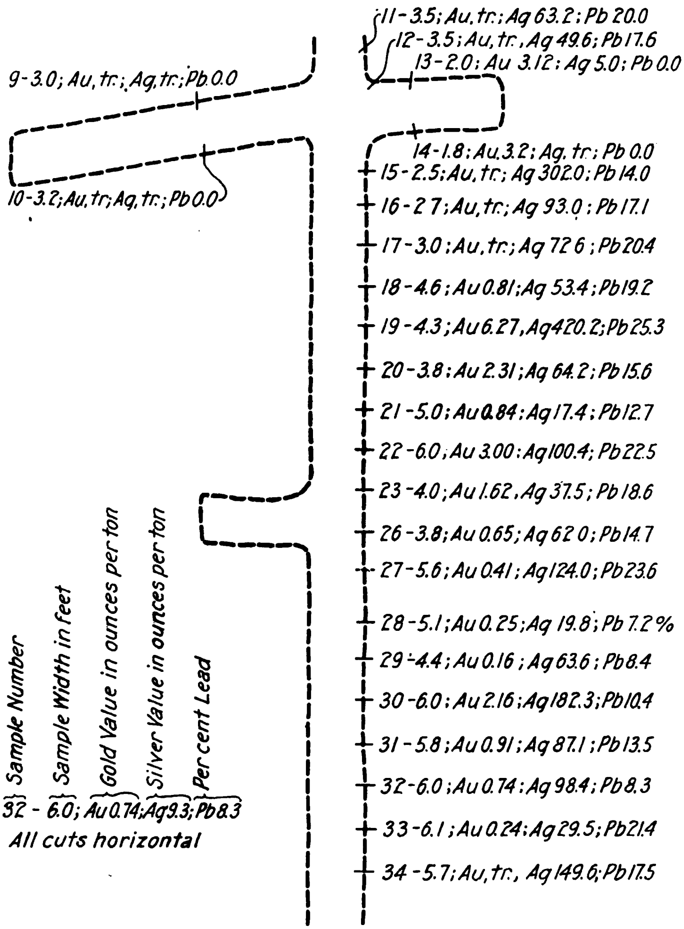

11-3.5; Au.tr.; Ag 63.2; Pb 20.0
12-3.5; Au.tr., Ag 49.6; Pb 17.6
13-2.0; Au 3.12; Ag 5.0; Pb 0.0
9-3.0; Au.tr.; Ag.tr.; Pb 0.0
10-3.2; Au.tr.; Ag.tr.; Pb 0.0
14-1.8; Au.3.2; Ag.tr.; Pb 0.0
15-2.5; Au.tr.; Ag 302.0; Pb 14.0
16-2.7; Au.tr.; Ag 93.0; Pb 17.1
17-3.0; Au.tr.; Ag 72.6; Pb 20.4
18-4.6; Au 0.81; Ag 53.4; Pb 19.2
19-4.3; Au 6.27, Ag 420.2; Pb 25.3
20-3.8; Au 2.31; Ag 64.2; Pb 15.6
21-5.0; Au 0.84; Ag 17.4; Pb 12.7
22-6.0; Au 3.00; Ag 100.4; Pb 22.5
23-4.0; Au 1.62, Ag 37.5; Pb 18.6
26-3.8; Au 0.65; Ag 62.0; Pb 14.7
27-5.6; Au 0.41; Ag 124.0; Pb 23.6
28-5.1; Au 0.25; Ag 19.8; Pb 7.2%
29-4.4; Au 0.16; Ag 63.6; Pb 8.4
30-6.0; Au 2.16; Ag 182.3; Pb 10.4
31-5.8; Au 0.91; Ag 87.1; Pb 13.5
32-6.0; Au 0.74; Ag 98.4; Pb 8.3
33-6.1; Au 0.24; Ag 29.5; Pb 21.4
34-5.7; Au.tr., Ag 149.6; Pb 17.5
Sample Number
Sample Width in feet
Gold Value in ounces per ton
Silver Value in ounces per ton
Per cent Lead
32 - 6.0; Au 0.74; Ag 9.3; Pb 8.3
All cuts horizontal

FIG. 32.—Shows the method of recording assay values upon a map of the underground workings. Such a plan, studied in connection with a map of the vein, Fig. 33, often brings out valuable facts.

the entire series and the folding may be indicated with considerable certainty as shown in Fig. 27. If there is no such easily identified bed the problem becomes more difficult and we must rely entirely on the dips and work out the probable folding by construction, taking care to choose the cases which seem most likely from the nature of the formation with which we have to do. For instance, with shale beds of isoclinal dip, we should rather expect excessive crumbling of a relatively thin bed than a much thicker one forming a simple fold, especially in an area that has been considerably disturbed.

From general knowledge of the nature of intrusive bodies we draw inferences as to the probable conditions beneath the surface; rocks of granitic texture probably belong to large masses and if the outcrop is small we would expect it to represent the upper portion of a batholithic mass or a stock which solidified at great depth. Other textures give rise to differing interpretations which influence the construction of the section in so far as igneous bodies are involved.

Further, the general sections give the relations of the ore bodies to the surface of the ground, which may be of considerable importance in the case of bedded deposits, or those dependent upon secondary enrichment, as the disseminated copper ores. Next the relation of the ores to the structure—folds, faults, and so on, will probably be brought out by these sections.

If the surface and underground maps are drawn to the same scale we may next start with the comparison of the surface and underground geology. As this is not usually the case, for our general ideas we rely upon the reduction of the chief mine workings to the scale of the surface map for use in the work of comparison. We may thus gain some idea as to what outcrops or portions of outcrops have been developed, what boundaries and faults have been cut underground, and in a general way what we may expect in further development work. For more detailed information it is necessary to plot the surface features where they would come on the different levels if constant in dip.

Such work is of a more or less speculative nature and should not be relied upon too much.

The maps of the mine levels are made on tracing cloth so that they can be superimposed to show the relations between two or three levels at the same time. In this way with the strikes and dips carefully plotted we can gain considerable information; faults, ore bodies, and boundaries may be identified from level to level, which assists in the construction of the sections. Taking the next step, when we have seen that a vein, for example, has preserved a fairly constant dip from surface to first level and perhaps only changes slightly from the first to the second level, we may tell where it should be found on the third. This may also be done with faults and to a lesser extent with boundaries. At least it will increase our grasp on the problem, and if we find that the expected condition does not prevail we at once begin to cast around for the reason and when we hit upon it the problem is once more in hand.

The comparison of the geological maps with the assay plans is a matter of great interest and importance; from the former we have the character of the country rock and the structural features, from the latter we see the distribution of the values. We may at once deduce valuable facts such as (1) the relation of the wall rock to the ore; (2) the influence of intrusives upon the deposit; (3) the relation of faults and fractures to the ore bodies. Or again we may determine the reason for the enrichment of certain portions of the formation. On the geological maps is gathered all the information that we have been able to obtain in the field regarding the nature of the ore. We may now see that the oxidized portions are richer and that these bear a certain relation to the ground water level.

In this connection there should be shown upon the section (or projection) lines representing in a general way the lower limit of the oxidized ores and the ground water level. (1) It may become apparent that oxidation has been influenced locally by the development of crushed zones and fracturing, or has been prevented in some way. (3) This comparison may bring out the reason for the occurrence of "shoots" or richer streaks in the ore. (4) When there are several periods of ore deposition and they have been indicated on the map (Fig. 33) it usually develops that certain ones have been more productive of values than others. This particular phase of the work is one of great importance and should be studied carefully in connection with the field notes on the subject.

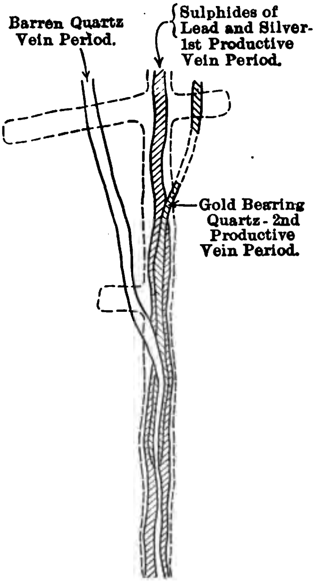

Barren Quartz Vein Period.
Sulphides of Lead and Silver-1st Productive Vein Period.
Gold Bearing Quartz-2nd Productive Vein Period.

FIG. 33.—This portion of a geological mine map shows three periods of vein formation, and should be studied in connection with the assay plan, Fig. 32.

As additional facts develop in the course of such work and tend to the formation of theories, it is well to go into the field occasionally and review conditions in the light of the new ideas. Often a little additional observation will confirm beyond question the conclusions reached in the office and points which were obscure or apparently unconnected will fall into their proper places in the general scheme. Then too the practical aspect of the matter is more emphasized and the tendency to carry theorizing to extremes is checked. From these considerations the importance of completing an examination and writing a report on the ground may be fully realized. The maps can be brought up to the date of the finished report; workings that have been opened as a result of preliminary recommendations may be visited and mapped to ascertain whether satisfactory results are being obtained.

In the course of the work of comparison described above we will be led to certain inferences regarding possible conditions; these should be carefully tabulated in the notes for reference in writing the report. At the risk of repeating some of the points mentioned above it may be worth while to take this matter up in more detail, with illustrations of some of the more common cases. In the case of sedimentary or bedded deposits the location of an ore body may sometimes be inferred when it does not outcrop, because we know its relation to the other members of the series. Frequently the section will give an idea as to the most likely place to prospect. In the case of the disseminated copper ores we are dealing with a problem of different nature. Such deposits are formed by the erosion of the upper portions of the mineralized area, the copper is carried downward in solution by the surface waters and deposited at or near the ground-water level. By this process of enrichment and concentration the "lean sulphides" are converted into ores of economic importance. Once the relation of the ground-water level to the surface is understood, it becomes possible to predict in a general way the depth at which the ore will be encountered.

When the study of the sections indicates a connection between the ore bodies and folding of a certain type we naturally look for some similar structural feature as an indicator of new finds: if the axes of folds show shattering and signs of mineralization in a district where deposits are known to occur along such lines it may be advisable to prospect such fractured areas even when the actual outcrops are insignificant. Similarly other structural features, such as faulting, may prove to be of great importance.

If it should appear in the course of the examination that certain impermeable beds are found near the ores we may assume that they have exerted a blanketing or confining influence. In beds of clayey shales for instance, there may be no outcrops of any importance and yet if such beds are associated with the ore bodies in some places, we may conclude that in other parts of the area even slight traces of mineralization in the shales may indicate the presence of ore in the more favorable underlying formation, which may be a limestone, for example.

In looking at the surface map we are sometimes struck at once by the fact that the outcrops of ore bodies show some marked relation to a particular formation; they may not occur outside its boundaries or they may be marginal to it. This idea of productive formations is very generally familiar; it is the determination of such associations and the reason for them that makes the geologist's work valuable. When the connection between the ore bodies and some rock mass is not so evident the inferences on the subject become even more important. For example, suppose that there are several intrusives of rather similar general character and appearance, but of different ages; if the ores are found to be associated with one of these the fact will develop only after the most careful field work to bring out the differences and represent the formations on the map. The complete solution of the problem may depend upon the microscopic examination of the thin sections. But in this case when the proper conclusions have been attained their subsequent application to mining problems will prove of great practical importance.

In going over outcrops, one may be led to the conclusion that certain minerals or groups of minerals are characteristic of the productive vein forming periods; or that such groups are characteristic of a certain vertical range in several veins. There may be veins of quartz or calcite which carry no values whatever, either when they occur by themselves or as portions of complex veins. When some such condition has been recognized the number of veins to be prospected may be cut down considerably.

It may be noticed that, for example, siderite, calcite and barite, associated possibly with a little galena, and stibnite, are found in the upper portions of a vein, which in this locality gives no good values. In other places, however, the same condition of affairs has been known to exist in veins which deeper show increasing amounts of galena and silver, and become productive. In such a case we may be led to infer that the proper horizon for development is at some distance below the outcrop which showed the mineral group above described.

By comparing surface and underground maps we see what has been discovered about the various outcrops with depth, and so may draw conclusions concerning the development of unprospected areas; the same thing is possible in the comparison of the different levels. If certain sets of conditions are found to produce valuable ore bodies, we must go over all the mapped areas to see where such conditions recur. It may be that the intersections of certain sets of fractures are usually productive and where such a point is found on surface it should be prospected if it shows any signs of mineralization. Underground when we see fractures cutting the drifts in such directions that they must all

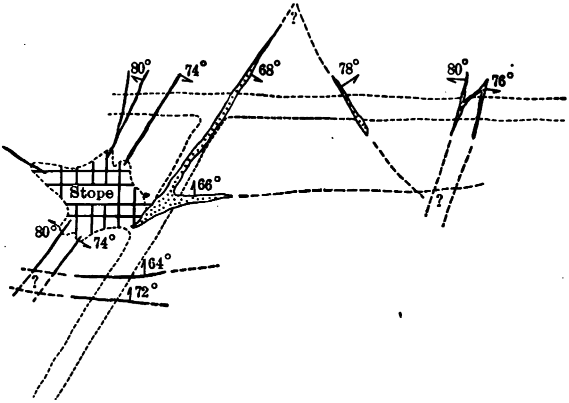


FIG. 34.—Shows the occurrence of an ore body at the intersection of fractures. Other possibilities are indicated by question marks.

intersect somewhere in the wall we are favorably impressed with the chance of making a find at the junction locality (Fig. 34). If dikes of a peculiar type are noted in the neighborhood of ore bodies they become valuable pointers; so also do particular types of alteration.

The facts that we ascertain regarding enrichment of certain portions of the deposit lead to very important inferences. If such phases of the development of the ore have been due to local causes we must draw our conclusions as to the probable extent of such richer bodies with some care. On the other hand, in dealing with the cases of general secondary enrichment characteristic of the arid regions, we may conclude that the chances of finding the richer ore near or above water level are good, and that when we pass into the lower or sulphide zone the values will decline, except possibly along fault lines for relatively short distances.

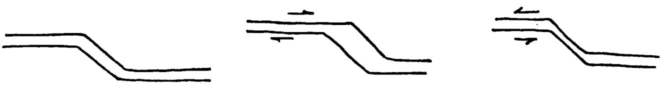


Fig. 35.—Diagrammatic illustration of the enlargement or constriction of an irregular channel due to movements of the walls.

When we try to explain the occurrence of "shoots" or richer zones in the ore body, we must look at a variety of possible causes and ask ourselves the following questions:

Is such an occurrence due to the country rock in this particular locality?

Is it due to the presence of an intrusive body?

Has it been determined by structural features, such as intersection with cross fractures or the enlargement or constriction of the channel due to movements of the walls? (Fig. 35.)

What effect had the earlier periods of vein formation on those which came later? It is possible that an earlier vein formation may have favored later fracturing, or may have offered more active chemical agents in the precipitation of values from solutions of later periods?

From the foregoing discussion it will be evident that the matter of drawing inferences from geological data is one which is dependent in part upon the observers general knowledge and his previous experience; but it should be chiefly affected by his ability to do original thinking along the most practical lines. As to general knowledge, it would seem to be a mixed blessing; there is a radical difference between the man of great erudition and the true scientist. The former may have a great number of facts, examples, and quotations at his command, but if he cannot go into the field with a clear and unbiased mind for the observation of new facts, he will make but a poor scientist, whose business is to observe, record, and interpret things as they are. If general knowledge and experience lead the geologist to draw hasty conclusions, without full investigation of conditions, or if they make him twist facts to suit theory, he will sooner or later make serious blunders.

Concerning Recommendations

Taking up the matter of recommendations a chance for a few generalities is offered. No hard and fast rules can be laid down for guidance and it would seem that perhaps the most desirable requisite is good common or "horse" sense. The geologist must restrain his tendency to theorize too much and yet must view the subject as broadly as possible. He will see perhaps hundreds of feet of development work that did not develop anything and that he thinks he would have saved. As a result he may lose sight of the fact that such work is quite expensive, and be led to advise prospecting that is not absolutely necessary. This may cause the "practical miner" to point the finger of scorn at him; mining men are much harsher in criticism of the geologist's unproductive development work than they are of their own.

Recommendations are of positive and negative character; some people rely largely on the latter, arguing that they get the fee just the same, and that what their clients "don't know won't hurt them" as long as money is saved. This method of "protecting clients" also prevents the making of mistakes—discovered mistakes, that is—and so ones professional reputation runs no risk of being impaired. But it does not look like the strictest honesty since it is known that most mines have benefitted at one time or another by the taking of what seemed to be long chances; consequently it would seem the best policy to size up the situation as carefully as possible and make recommendations according to the possibilities, stating clearly the element of chance that must enter to a greater or less extent into work of this nature.

To get down to the detailed phases of the question, recommendations cover, first, the abandonment of work along wrong lines, such as (1) surface and underground prospecting in unfavorable formations; (2) surface and underground prospecting of unproductive veins; (3) development work at unfavorable horizons; (4) wrong methods of development work.

When it has been determined that a formation is not productive and there are well established reasons why this is the case it is best to stop work along such lines and concentrate it on the more productive areas.

Under the old practical ideas as to "where the ore is" little logical distinction was made between vein types, the supposition being that any lead might anywhere "open up" and be productive. When it is clear that some fractures have been formed after the chief periods of ore deposition, even though they carry quartz and possibly other gangue minerals, it is well to leave them as a last resort, and if they have been developed to some extent without showing anything, further work is a waste of money. There often are several vein types ranging from barren to productive and recommendations should always provide for the exploration of the latter first; if they prove up well then a certain amount of attention may be given to the less promising ones to make sure that nothing is being overlooked.

From certain considerations which will be developed in a later chapter it would appear that there is a vertical range or variation in the nature and value of an ore deposit, and it is almost needless to say that any scheme of development should provide for the concentration of work at the more productive horizon.

The usual methods of planning development work seem to depend first upon the previous experience of the operator and second upon haphazard ideas as to the nature of the ore bodies and their occurrence. If a miner comes from a district where it is the fashion to drive crosscut tunnels, he is extremely fond of crosscutting. This is not a good way to develope irregular bodies or "chimnies," which had best be followed down from the ourcrop, after the Mexican method, until some idea has been gained of their extent and mode of occurrence. When the value of diamond drilling has been one of the articles of a miners early creed, he will drill upon the slightest excuse or none at all and will probably keep very indifferent records of the work. In vein formations where the values are "spotty" and "high grade" it is taking long chances to put a hole of two square inches section into the vein with the idea of finding out anything about its values. In most cases you will be lucky if the vein can be recognized when it is cut especially if the gangue minerals are similar to those of the country rock, as in the case of a quartz vein in a granite porphyry.

Again when the ore bodies are of the "chimney type" the chances of striking one with a diameter of say 20 ft. with a single hole or even with a regularly spaced series of holes, are poor. If the ore forms along relatively flat dipping fractures or bedding there is danger of the hole following along in the plane of the ore and so giving an entirely wrong idea of its extent. Diamond drilling is alright in the proper place but it is by no means a panacea for mines suffering from depletion of ore reserves.

On the other hand recommendations cover the methods of prosecuting development work along the most promising lines, such as: (1) Surface prospecting to give information as to the identity of unrecognizable vein types; (2) the concentration of development work in the most favorable formations, to the probably productive veins, and at the best horizons; (3) the planning of drifting or crosscutting to reach ore bodies in the best way reasoning from the conditions controlling their occurrence and form.

Instead of going at the question blindly the geologist studies his maps and outlines the new work with reference to the conditions shown there; if the mineralization has taken place along a "linked vein" zone, the scheme should include crosscutting at intervals to determine the true walls of the ore body. Where the ore occurs in irregular masses determined by intersecting fractures, perhaps the best plan would be to drift parallel to the main set and watch carefully for the transverse leads, along which short crosscuts should encounter the productive junctions. In case flat leads seem important the plan of work should provide for raises at frequent intervals.

Besides these general cases many others will occur in the field each calling for different treatment, but all may be handled in the same general way, always remembering that a thorough grasp of the fundamental conditions is necessary to make intelligent recommendations. In addition to the cases cited it is also necessary at times to advise as to the best methods to open up ore bodies deformed by complicated folding, or offset by faulting. The means of locating such bodies will be discussed in connection with geological measurements.

CHAPTER VIII

GEOLOGICAL MEASUREMENTS

From a geological surface map we can scale directly in horizontal projection, the lengths and widths of the exposed portions of beds, veins, and faults; we can also measure the areas of different formations, which may be of value for subsequent calculations or discussions. In these respects a geological map is no different from any other plan.

In addition, however, a topographic and geologic map gives information which has to do with a third dimension, the vertical, and this brings into consideration those methods of measurements which have to do with the determinations of the probable location of geological features at different levels, either on the surface of the ground or beneath it. Thus, it may be of great importance to determine the location of an outcrop which has been hidden by a thin mantel of soil or buried in the wash of a river valley. In making recommendations as to methods of development work, it is of great value to have an idea as to where a given bed, vein, fault, or contact may be encountered upon a certain level of the mine, so that we may gain some idea of the direction and length of the working necessary to explore it. The questions which arise for consideration are as follows:

1. What are the effects of topography upon dipping or inclined beds, etc.?
2. What may we expect from the migration of dipping beds or veins with depth; and
3. What are the effects of displacement, due to faulting?

For most practical purposes it will be sufficiently accurate to regard any given bed, vein, or fault, as a plane, neglecting the minor irregularities or rolls which usually occur. The main idea to be borne in mind discussing the first two questions given above, is that in following down an inclined plane, the component movement in a horizontal direction takes place in the direction of the dip. That is, if you follow an east dipping vein down hill, it will migrate or the outcrop will be exposed more and more to the east from the original point. In ascending the reverse is true. The effect of topography upon an outcrop is indicated in Fig. 36. In passing from a higher to a lower level under ground it is quite apparent that a dipping bed or vein will appear further removed in the direction of the dip. The method of determining the probable location will be taken up later.

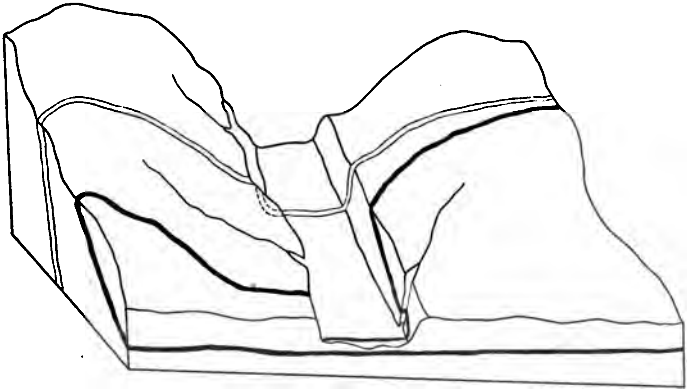


FIG. 36.

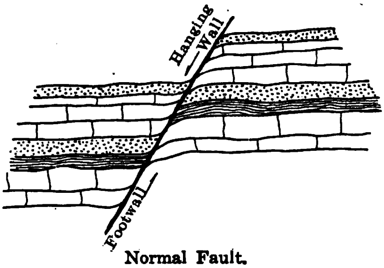
Faults.—A "fault" is a fracture or break along which there has been movement of the walls.

The upper wall is called the overhanging wall or simply the "hanging wall." The lower wall is called the "foot wall" or "foot."

When the hanging wall has moved downward with respect to the foot wall the fault is said to be "normal." If the reverse is true, the fault is called a "reversed fault." See Figs. 37 and 38.

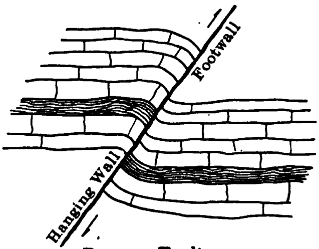
If the fault plane is parallel to the strike of a faulted formation, the fault is called a "strike fault"; if parallel to the direction of the dip it is a "dip fault"; while if the fault plane makes an angle with the directions of both strike and dip an "oblique fault" results. (Refer.: Chamberlain and Salisbury, *Geology*, Vol. I, page 522, for descriptions and diagrams illustrating the effect of faulting and erosin upon outcrop.)

If we consider as an extreme case a small lens of ore, for example, cut by a fault, we may regard it for purposes of discussion as a point. If the formation involved is one of uniform character, it is clear that there will be no means of determining where the part cut off by faulting will be found. Thus Fig. 39 represents an indeterminate case. It is known that if the hanging wall has moved down, the lost point will lie somewhere along the fault plane as shown in the strike projection or "end view"; but it may have moved up or down or to either side, or have been subjected to a combination of vertical and lateral movement. If grooving or striation of the fault plane was noted, an idea may be gained as to the direction along the fault plane in which the lost point may be encountered, provided it was not carried up into a portion of the fault now eroded, but the problem is extremely indefinite. Fortunately we have usually some means of telling the direction and extent of the movement; this may be done by noting the displacement of beds, dikes, or veins and by the character of the fault breccia (Refer.: J. E. Spurr, Geology Applied to Mining, page 151). It is the measurements based



Normal Fault.

FIG. 37.



Reverse Fault.

FIG. 38.

upon the displacement of such features which will be taken up in the following discussion.

In the next case, Fig. 40, it will be assumed that we are dealing with a "strike fault," and that there is an easily recognizable bed, identified as shown at a and a′ in the strike projection or "end view," which is also a section. The faulted portion *P′* of the body *P* will have been moved as far vertically as the faulted point *a′* of the bed *a*, and hence must lie at the level indicated on the strike projection. Upon the dip projection, the direction of the striæ indicates the lateral movement of the faulted portion so that *P″* gives its desired location.

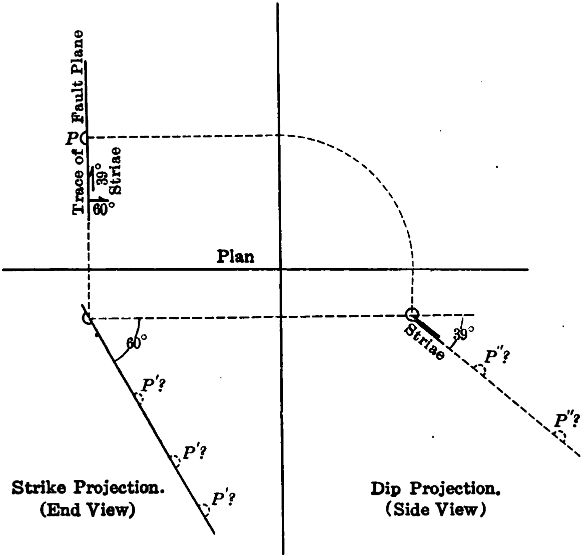


Fig. 39.

In a vertical section perpendicular to the fault plane as in the figure under discussion, the distance *PP′* is called the "total throw"; x is the "vertical throw"; and y the "horizontal throw." (Refer.: C. F. Tolman, Jr., *Economic Geology*, Vol. II, page 509.) To complete the terms given in this connection by Mr. Tolman, the "perpendicular throw" is the distance between faulted portions measured perpendicular to the intersections of faulted planes, with the vertical section; the "parallel throw" is measured parallel to the faulted plane, these distances are *a–b* and *a′b* respectively of Fig. 40.

In the case just discussed it was necessary to rely upon the fault striæ to gain some idea as to the horizontal component of the fault movement in the plane of the fault. Since the striæ are often the result of purely secondary movements, and at best represent only the latest movement along a fault plane, it is desirable to have some other means of measuring the horizontal component. Steeply dipping dikes or veins are most satisfactory for this purpose. In Fig. 41 the dike, *D*, which is nearly perpendicular to the fault plane, serves as an index; it is assumed that enough data is available to plot the position of the dike and its faulted portion as shown upon the dip projection which is really a vertical section. The horizontal component (really "horizontal displacement," see below) cannot be obtained directly by measuring the distance between the two portions of of the dike at any level whatever. Having the "vertical throw"

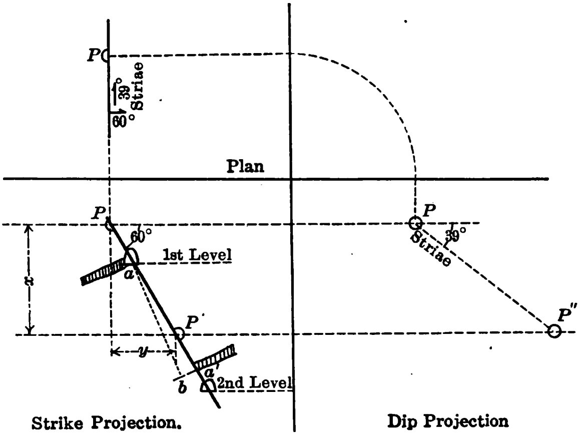


FIG. 40

from the previous case we must measure down that distance vertically from D and then take f as shown, giving the horizontal component of the fault movement which is to be laid off from P_1 to obtain the desired location of P''. Since we know from the preceding case, the distance y and from this construction the distance f, it is easy to calculate the coördinates of the new point, P'', with respect to the original point P. The level at which P'' will be encountered, of course depends upon the vertical throw x of Fig. 40.

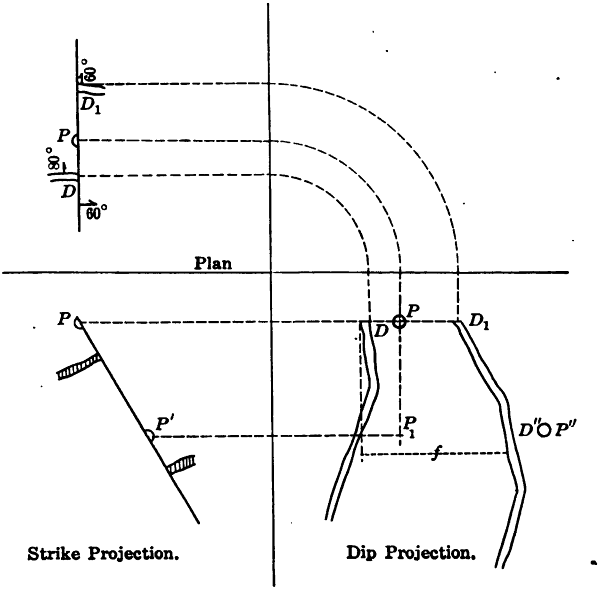


FIG. 41.

The foregoing discussion has treated of cases where the beds used as means of measurement are cut by the fault plane in the direction of their strike and the dike used in measuring the horizontal component is perpendicular to the fault plane. In Fig. 40 the fault is a strike fault and in Fig. 41 as regards the dike the fault is a dip fault. In Fig. 42 we take up the case of an oblique fault and see that the question becomes more complicated since the projection would show given portions of the index bed and the dike as quadrilaterals instead of lines, that is, the projections could not be regarded as sections. Thus the graphic solution becomes indefinite. The best thing to do in such a case is to first plot the intersections of the original and faulted portion of the index formation upon the plane of the fault. This may be done graphically as indicated in Figs. 43 and 44.

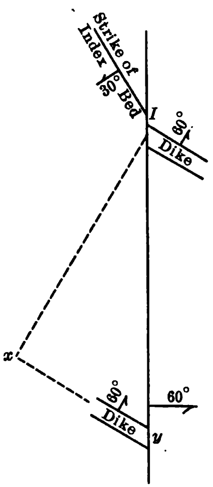


FIG. 42.

Elevation lines are ruled upon the horizontal projections of the fault plane and the bedding plane, which have the point *I* in common, where the elevation lines marked 5, intersect, there is another point in common between the two planes, thus the intersection line *I–J* is determined. To determine the position of *I–J* upon the fault plane for further measurements, it is only necessary to plot the measurements *IA* and *BC* of Fig. 43 as shown in Fig. 44. Without going through the construction to determine the intersections of the two parts of the dike with the fault plane, they may be taken as shown.

It is assumed that the bed and dike are constant in strike and dip and that the fault movement has produced the same amount of displacement everywhere along the fault plane. Consequently the traces of a faulted formation upon the fault plane will be parallel as indicated in the figures. Any given point such as *P* must maintain its position relative to the faulted bed, so that it will fall along the broken line, parallel to *I'J'*; similarly the distance from the dike must not change and so *P'* may be located as shown. From the plan of the fault plane, the vertical projection or section may be constructed and the measurements previously defined may be taken. The horizontal plans may also be constructed; the measurements for such a plan are defined below.

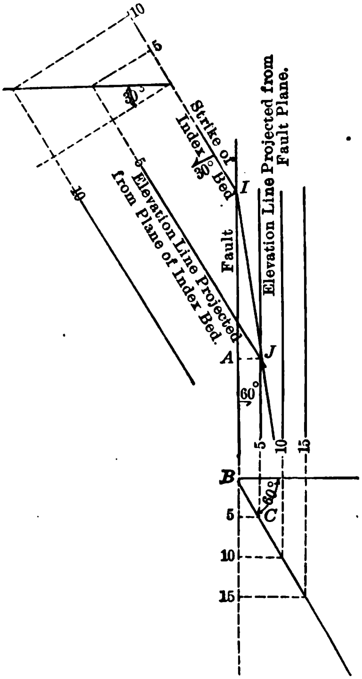

10
5
30°
Strike of Index Bed
30°
5
10
Elevation Line Projected from Plane of Index Bed.
Elevation Line Projected from Fault Plane.
I
Fault
J
A
60°
5
10
15
B
60°
C
5
10
15

FIG. 43.

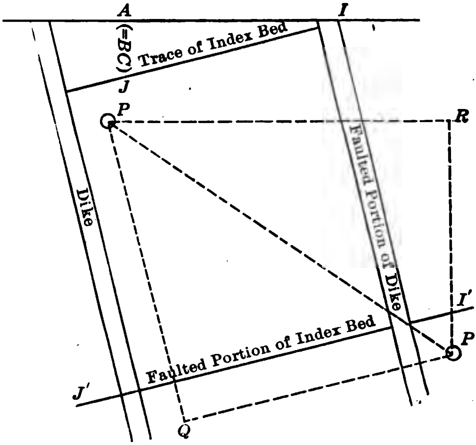

A
I
(=BC)
Trace of Index Bed
J
P
R
Dike
Faulted Portion of Dike
I′
P′
Faulted Portion of Index Bed
J′
Q

FIG. 44.

Referring again to Fig. 44 *PP'* is called the "total displacement"; *PR* is the "horizontal displacement"; and *P'R* is the "vertical displacement." Other measurements which may be taken in the plane of the fault are *PQ*, the "perpendicular displacement" (measured perpendicular to the trace of the faulted bed) and *P'Q*, the "parallel displacement" (parallel to the trace of the faulted bed).

The "perpendicular separation" is the distance between the two portions of the faulted formation measured perpendicular to their planes, or their planes produced. These measurements are not illustrated in the figures; in Prof. Tolman's paper referred to above, other "separation" measurements are given which are omitted here.

Regarding Fig. 42 as a plan, such as a map, *IY* is the "total heave," *IX* is the "perpendicular heave" and *XY* is the "parallel heave." Heaves are the shifts of index beds (or other features, dikes or veins) shown in a horizontal plan or section.

An endless variety of fault problems may be met with in the field and often not enough measurements can be taken to solve them satisfactorily. A graphic representation of the known facts will usually be of great assistance in working over such problems and it is to be hoped that the suggestions made here will be of value more as illustrating the method of solution, than as an attempt to give an exhaustive discussion of the subject. The idea of using the method of descriptive geometry in these cases was suggested by the paper by Prof. Jos. W. Roe, which may be found in Chapter IX.

In solving problems of this type cross-section paper is most convenient since it does away to a large degree with the use of a scale. With a protractor graphic trigonometric solutions may be made rapidly without recourse to tables. For instance, suppose it is desired to find the distance that a dipping vein will "migrate" horizontally with a given depth. Assuming a section at right angles to its strike, the angle of dip may be plotted, the vertical distance scaled, and the required horizontal distance is determined directly by measurement.

CHAPTER IX

APPLICATION OF DESCRIPTIVE GEOMETRY TO MINING PROBLEMS[1]

BY JOSEPH W. ROE,[2] NEW HAVEN, CONN.

Many questions arising in the work of the mining engineer may be solved quickly and with sufficient accuracy by the methods of descriptive geometry; but, unfortunately, this subject is more often considered from a mathematical view-point than as an effective tool for solving practical problems. Some of the principles involved are merged into the ordinary operations of mechanical drawing, and are used unconsciously by the engineer in his every-day work. The rest are stowed away on the book-shelf with his forgotten or rarely-used college text-books. One reason for this condition of "innocuous desuetude" may lie in the unfortunate and often cumbersome notation which it has been found necessary to introduce. If some of these principles can be recalled to the engineer's attention in terms of every-day use they may prove of practical bearing.

Recently, in talking with several mining engineers, I used some of the drawing-room methods of a machine-designer, to the evident surprise of those around me. These men were perfectly familiar with the methods, but their application to mining-work had not occurred to them. At their suggestion the present paper is offered, not in any way as a treatise, but merely to suggest a certain point of view, in hope that it may lead others far more familiar with mining-problems to pursue the subject further.

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[1] This paper was presented at the Pittsburg meeting of the American Institute of Mining Engineers, in March, 1910, and afterward published in the "Transactions" of the Institute.

Although some of the discussions are of mining rather than geological problems, it was thought desirable to republish the paper as a whole, because of its value to mining engineers as well as geologists.

[2] Assistant Professor of Mechanical Engineering, Sheffield Scientific School, Yale University.

I. **To Find the Strike.**—As the simplest and most fundamental problem, let it be required to find the strike of a vein when the location and elevation of three points on the outcrop are known. It will be assumed for the present that the vein is a plane.

In Fig. 45 let A, B, and C be three points on an outcrop, their elevations, as found by observation or shown by contour-levels, being as noted. Connect A and B, B and C, giving the plan-view of two lines lying in the plane of the vein. If a side-view be drawn, as shown beneath the plan, A, B, and C will appear as A_v, B_v, and C_v (the v-subscript indicating a vertical projection), and a horizontal plane through A will appear as a horizontal line through A_v. D_v, where the line B_vC_v cuts the plane, is the side-view of a point in the vein on the same level as A. Projecting up to the line BC, this point appears in the plan-view at D. Two points in the plan-view, such as A and D, on the same level and both in the vein, determine the strike. A saving in line-work might be made by drawing the line representing the side-view of the horizontal plane through A itself instead of through its projection, A_v, using the same construction otherwise. It is clearer, for the present purpose, to show the side-views separately instead of partly superimposed.

If a point on the outcrop at the same level as A can be located, as C', the line from A to C' will at once give the strike. A third point, B, will, however, be necessary to determine the dip, as a plane cannot be located with less than three points.

II. **To Find the Dip.**—Having found the strike, take a side-view of the vein looking up the strike-line. The points A, B, C, and D and the plan-view will appear as shown. The line through B'_v, C'_v, etc., Fig. 46, is the edge-view or end-projection of the vein, and the dip is, of course, the angle included between this and the horizontal plane.

The dip might also be found by passing a vertical projecting-plane through B' perpendicular to the line of strike, and then revolving the line of intersection of this plane and the vein into the plane of the paper. This is the characteristic method of

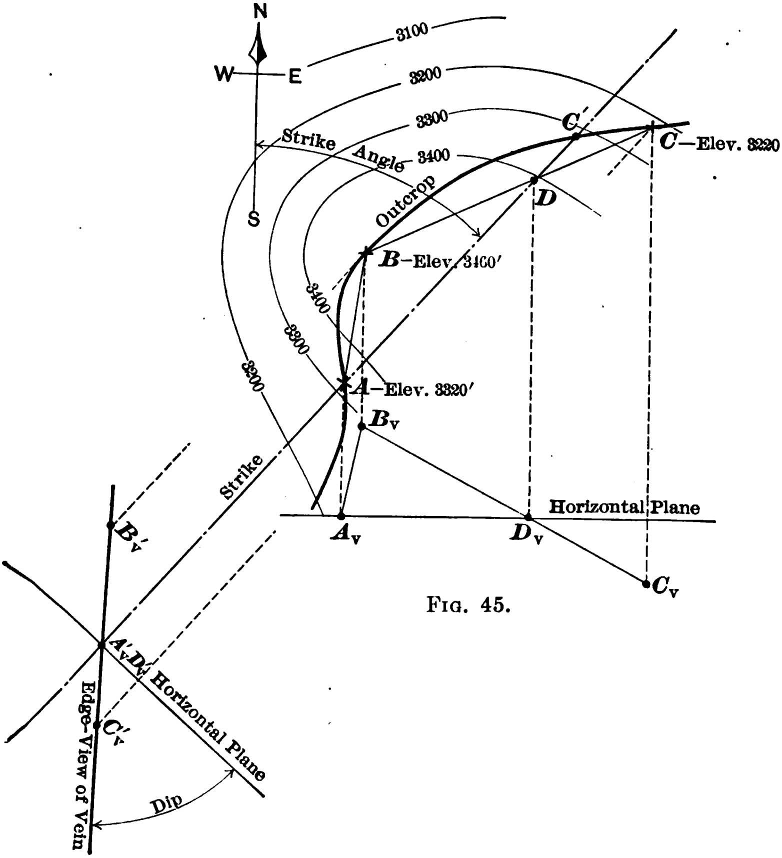


FIG. 45.

FIG. 46.

descriptive geometry, but when the engineer wants to detail some part which stands at odd angle with the rest of his drawing, as, for instance, a hand-hole plate or a sky-light, he does not adhere rigidly to his right-angled projections, but draws an oblique view looking squarely at the detail, showing it directly and giving the dimensions without any troublesome revolvings. By taking a side-view up the line of strike many problems which otherwise might be troublesome are reduced to the very simplest terms. As examples of this take the following:

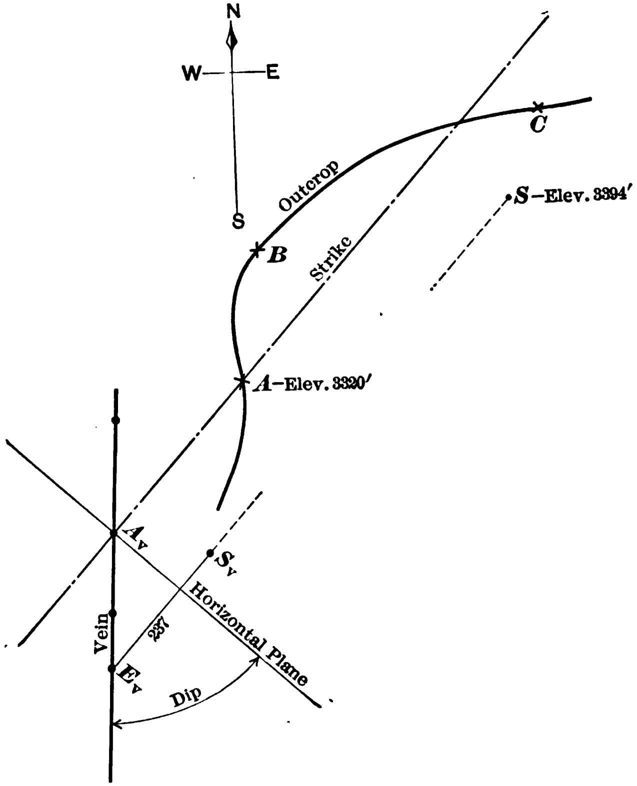


FIG. 47.

III. **Depth of a Shaft.**—Given the points on an outcrop as before, how deep must a shaft be sunk at some point, S, to strike the vein?

The strike and dip having been found, we have the side-elevation of the vein, as shown in Fig. 47. The point, S, from which the shaft is to be sunk appears as S_v at its proper elevation, and the depth of the shaft is obtained at once by scaling S_vE_v.

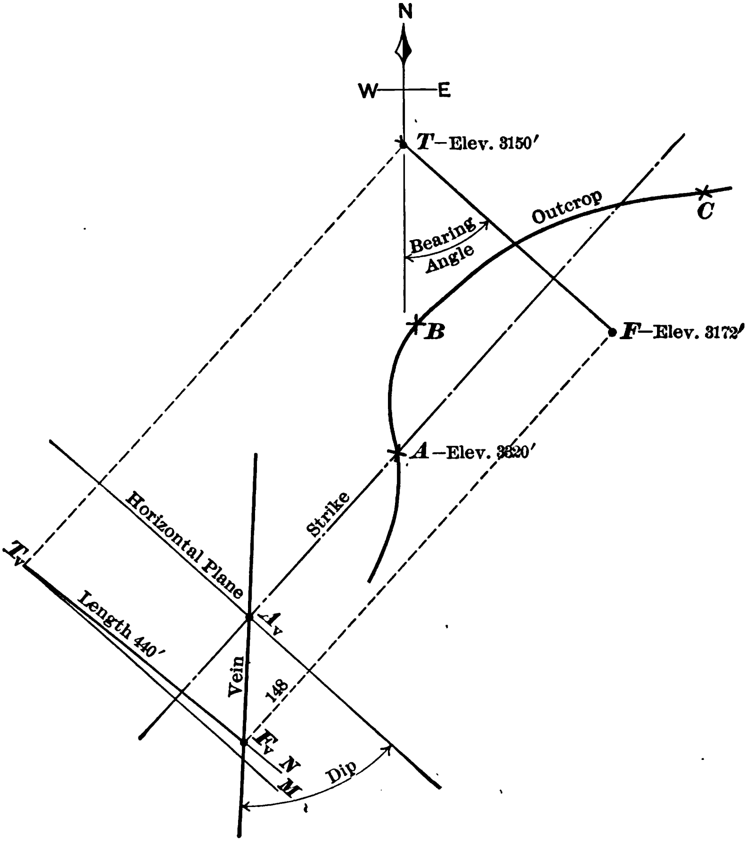


FIG. 48.

IV. **Length of a Tunnel.**—Suppose it is proposed to drive a tunnel with, say, a 5 per cent. upgrade from some point, T, Fig. 48, to the vein. Where will it hit the vein, how long will it be, and what will be its bearings?

Find the strike and side-view. Project the point T to T_v. Draw a line, T_vM, parallel to the horizontal plane, and T_vN, making an angle with T_vM corresponding to the grade. T_vFv is, to scale, the length required. In the plan-view it is obvious that the tunnel will appear at right angles to the strike, which gives at once the bearing-angle. Project F_v up to meet this line, as at F, and we have the plan-view of the point of intersection of the tunnel and the vein. The elevation of F may be obtained by trigonometry, or more simply still by scaling the difference in level between F_v and the horizontal plane through A_v.

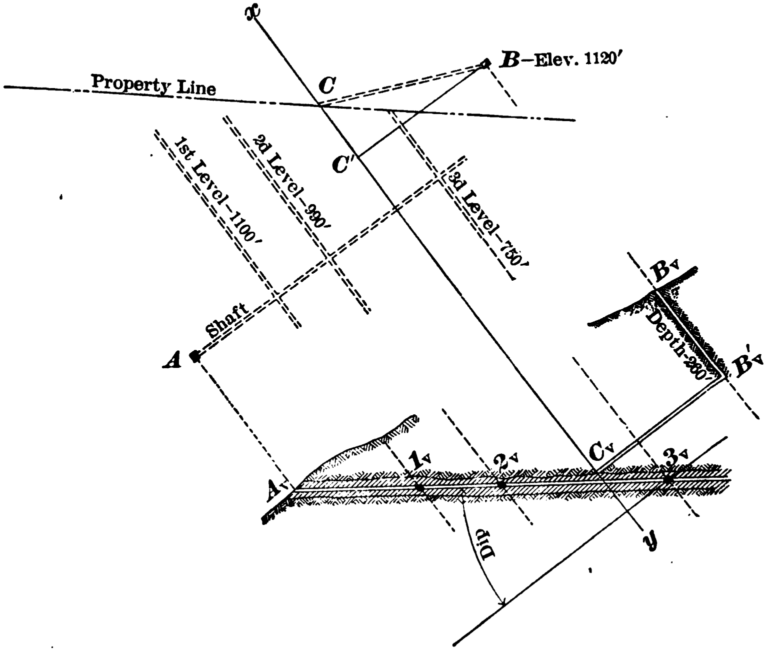


FIG. 49.

V. **Location of a Tunnel.**—Let A, Fig. 49, be the mouth of an inclined shaft and 1, 2, and 3 be drifts from it, both shaft and drifts following the vein. B is a vertical prospecting-shaft of a certain depth on an adjoining property. What will be the direction and length of the shortest drift from the bottom of B to pick up the vein and still keep on the "B" side of the line?

The drifts 1, 2, and 3 are presumably horizontal, and since they lie in the vein they are parallel to the strike. In the end-view they will appear as 1_v, 2_v, 3_v, and will determine the end-view of the vein, the vertical shaft, B, appearing at B_v B'_v. A horizontal line from B'_v will cut the vein at C_v. The line XY through C_v, parallel to the levels, is the plan-view of the intersection of the vein and a horizontal plane through B_v, and any horizontal drift from B'_v must intersect the vein somewhere along this line. In the plan-view the shortest drift would be BC'. But BC' would run out of the property. BC therefore would be the limiting position of the drift to have it entirely on the "B" side of the line.

VI. **To Find the Bearings of a Shoot.**—Suppose we wish to find the bearings of a shoot in the vein *ABC* of Figs. 45 to 48. Let the shoot appear on the outcrop at B, Fig. 50, and have a pitch of 19° down toward the *NE*.

A side-view of the point B will show B_v 140 ft. above the level of A. Any line through B with a pitch of 19 degrees from the horizontal must cut the level of A at a distance of mn from the foot of the perpendicular through B_v. All points in the vein on the same level as A lie somewhere along the strike-line. With B as a center and mn as a radius swing the arc XX, cutting the strike-line at some point, S. Connecting B and S, we have the bearing of the shoot. In the case shown we would expect the shoot to reappear on the outcrop at T. This construction might be used to locate a possible reappearance of a shoot in rough country overgrown with underbrush.

A somewhat similar construction would give the bearing of a drift, lying in an inclined vein and itself inclined at some grade angle, say 10 per cent. Lay off to scale in an end-view a parallel 10 ft. above a horizontal through A_v. Project D_v, the intersection of the parallel with the vein, to intersect an arc, yy, of 100 ft. radius swung from A, as at D. AD is the bearing desired.

VII. **To Find the Thickness of a Vein.**—Given the outcrop and dip of the hanging- and foot-wall, how thick is the vein and what is the strike?

Case 1.—Let the side-wall be vertical. Let the outcrops be as shown in the side-view of Fig. 51, their intersections with the ground or other horizontal plane being A_v and B_v. In the plan the side-wall appears as a line. Project A_v and B_v to A and B.

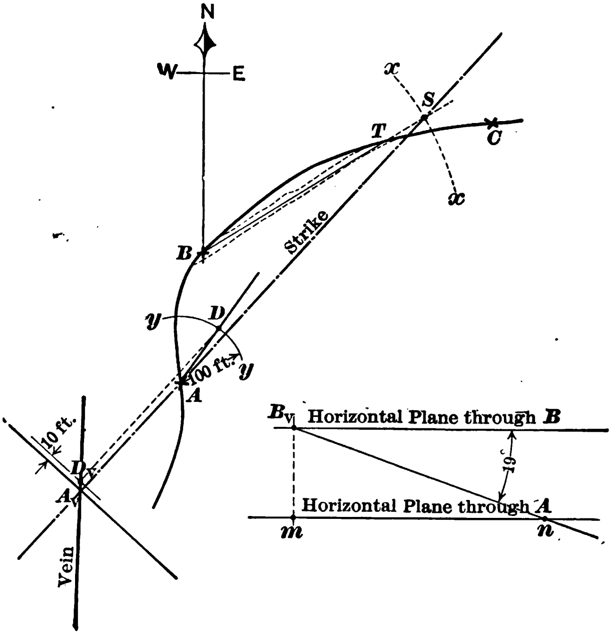


FIG. 50.

Draw any line, yy, cutting the walls at C_v and D_v. Through C_v and D_v draw C_vn and D_vn_1, making the given dip angle with the horizontal. The perpendicular distance between these lines is the thickness of the vein. The strike would, of course, be perpendicular to the direction in which the dip is measured. A construction giving it more accurately would be as follows: Any plane through C_v having the given dip angle must cut the

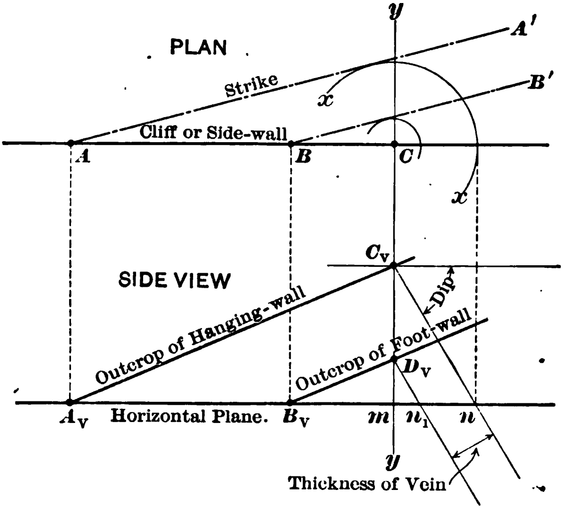


FIG. 51.

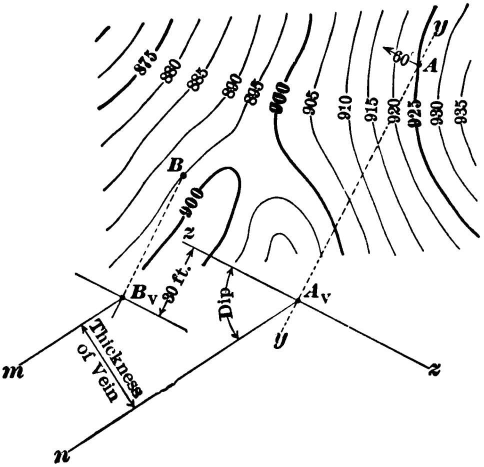


FIG. 51a.

horizontal plane at a distance *mn* from *m*. With *C* as a center and *mn* as a radius swing the arc *XX*. The strike-line, *AA'*, passes through *A* tangent to *XX*. *BB'* is parallel to *AA'*, or it may be found in the same manner as *AA'*.

Case 2.—Let the surface be irregular, as, for instance, in Fig. 51a. Let the location and elevation of *A* and *B* and the angle and direction of dip be as shown. Draw a projection-line, *yy*, perpendicular to the direction of dip. Draw any line, *zz*, perpendicular to *yy*. Letting A_v be the side-view of *A*, lay off the dip angle as shown. Lay off B_v on a projecting-line parallel to *yy* at a distance of 30 ft. below *zz*. Through B_v draw B_vm parallel to A_vn. The perpendicular distance between these lines is the thickness of the vein.

VIII. **To Find the Limits of an Ore-Dump.**—Given the location of a shaft or tunnel, *A*, Fig. 52, on a certain contour-level as shown, to find the outer limits of a dump formed by filling in on a level with *A* for a certain radius, say 200 ft.

With *A* as a center and $AD = 200$ ft. swing an arc, *BC*, cutting the contour-level of *A* at *B* and *C*. The area between this arc and the contour through *A* is, of course, the top of the dump. Between *B* and *C* the side of the dump will extend down hill a varying distance, depending on the angle of rest of the material and the contour of the surface. Draw an auxiliary view showing a vertical section of the face of the dump. The sloping side appears as the indefinite line, D_vE_v, at an angle equal to that at which the material "hangs up," say 40 degrees. Draw a series of levels, *aa'*, *bb'*, etc., corresponding to the contour-lines of the map, and to the same scale.

The side of the dump is a portion of a cone, with a vertical line through *A* as its axis. The top of the dump and the various levels, being parallel planes, cut the cone in a series of circles concentric with the axis. All points on the surface of the ground at an elevation of 980 ft. lie on the 980-ft. contour-line, and all points on the face of the dump at 980 ft. elevation lie on an arc concentric with *BC*, and having a radius *aa'* greater than that of the top. Wherever this arc meets the 980-ft. contour, as at 1, 1,

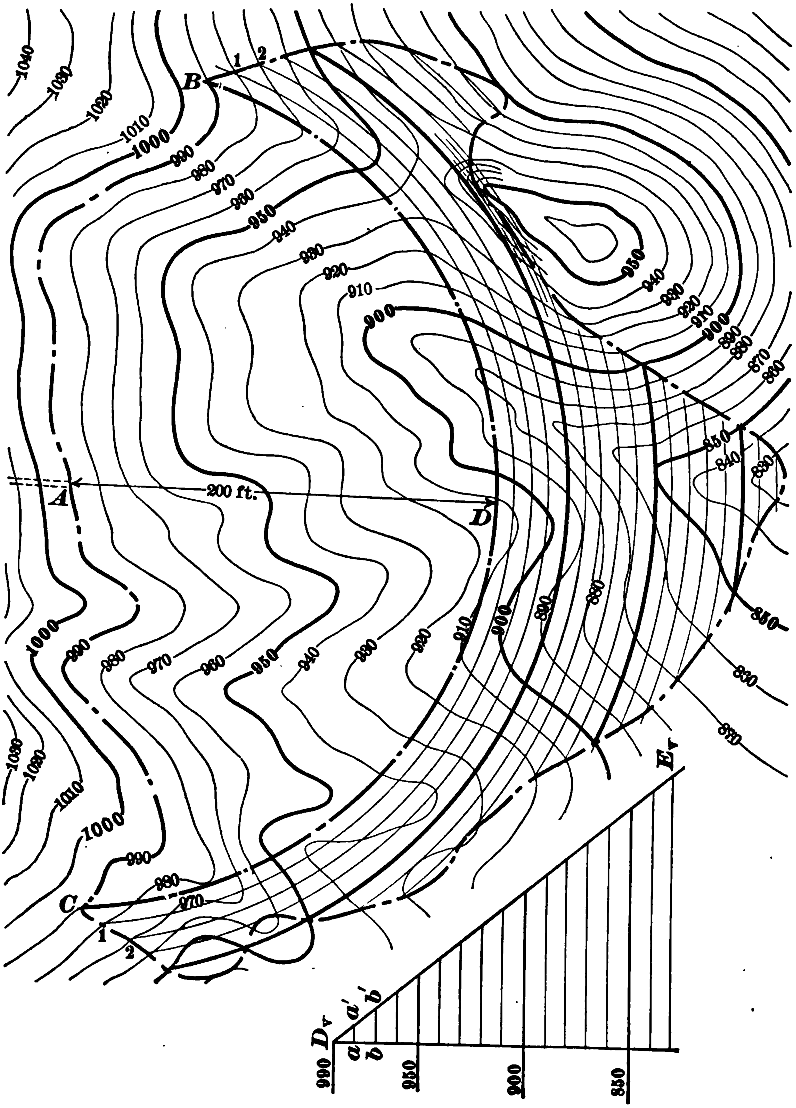

1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
910
900
B
1
2
950
940
930
920
910
900
890
880
870
860
850
840
830
A
200 ft.
D
1000
990
980
970
960
950
940
930
920
910
900
890
880
850
830
810
1030
1020
1010
1000
990
980
970
C
1
2
E_v
D_v
a
b
a'
b'
990
950
900
850

FIG. 52.

there is a point on both the face of the dump and the surface of the ground. The remaining points, as 2, 2, etc., may be located by swinging the arcs from *A* or by measuring the increase in the radius, as *bb'*, etc., out from the arc *BC*, to cut the proper contour-line. Connecting the series of points so located, we have the completed outline of the dump.

There may be places where the edge does not cross a contour for some distance. Any uncertainty as to its location may be cleared up by interpolating on the ground and on the face of the dump, as shown on the shoulder of the knoll.

With the limits located and the surface-contours on the face drawn, calculation of the tonnage becomes a mere matter of mensuration. The area of the dump at each level is readily obtained from the contours with a planimeter. Each area will be bounded by a circular arc along the face of the dump and the corresponding irregular contour-line where the dump is in contact with the ground. The volume of each layer may be found by the end-area method or by the prismoidal formula.

IX. **Ore-Dump on a Property-Line.**—In practice the problem might easily occur in the reverse form. Given a point, *A*, Fig. 53, from which it is desired to fill, and a property-line, *XXX*. How much tonnage-capacity is there available in filling out to the line and extending, say, 200 ft., as before, wherever the property-line is not encountered? In the previous case the upper edge of the dump was regular and the outer one irregular. In this, the limits of a portion of the outer edge are set by the property-line, and the upper edge will, in consequence, be irregular.

As before, we have the crest of the dump starting out from *B* and *C*, Fig. 53, the two points on the contour through *A* at the given limiting distance of 200 ft. For a short distance the crest will be circular, with its center at *A*, and the outer edge will be found as before. It is evident, however, that the crest cannot swing out far before the property-line is encountered. To determine the side of the dump where it is affected by the side-line we may proceed as follows: Draw an auxiliary side-view. The level of the top, 990 ft., appears as shown, also the side of the

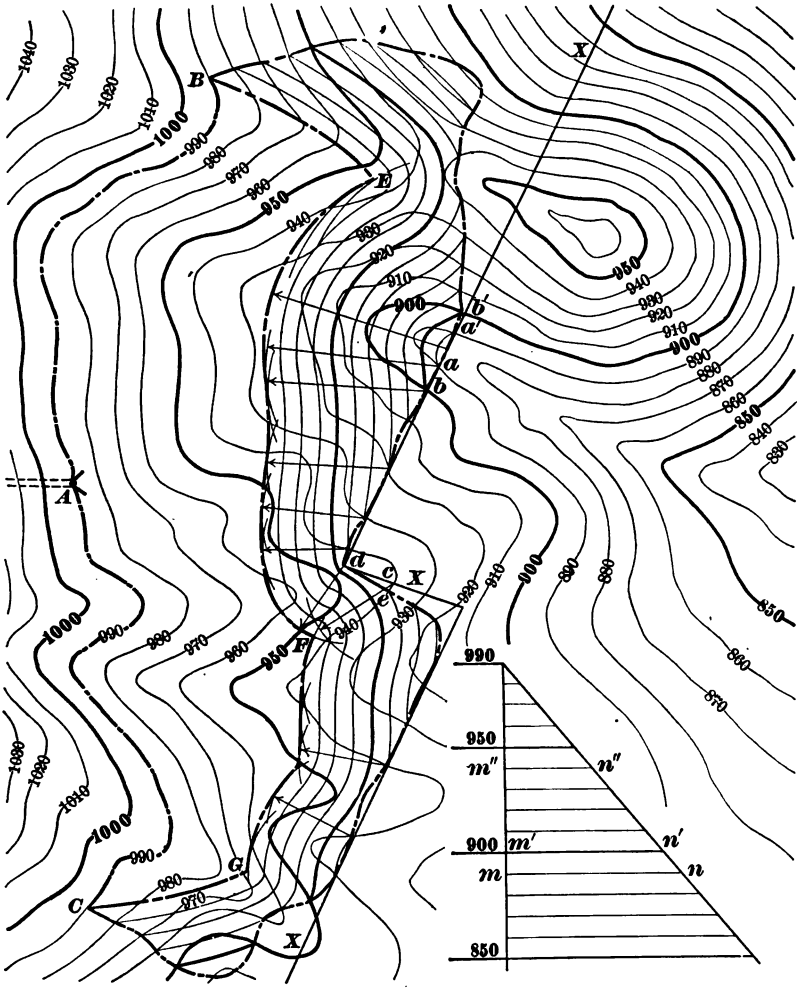

X
B
E
A
C
G
F
X
X
a
b
a'
b'
c
d
e
1040
1030
1020
1010
1000
990
980
970
960
950
940
930
920
910
900
890
880
870
860
850
840
830
990
950
m''
n''
900
m'
n'
m
n
850

Fig. 53.

dump and the parallels corresponding to the contour-levels of the map. For any points on the property-line, such as *a* and *a'*, which are on the 890-ft. level, it is evident that a vertical projection of the crest cannot come within the distance *mn* of *a* or *a'* without having the dump over-run the side-line. From *a* and *a'*, then, swing arcs with *mn* as a radius. These arcs limit the position of the crest so far as *a* and *a'* are concerned. Similarly, for *b* and *b'* on the 900-ft. level, arcs swung with *m'n'* as a radius locate the crest so far as *b* and *b'* are concerned. Continuing this process for the intersection of each contour-line and the property-line, we obtain a series of arcs. The innermost arc, or the one toward the uphill side, limits the crest. Drawing a fair line tangent to the inside arcs, we have the crest *EFG*. An arc not used, such as that from *c*, indicates that as far as *c* is concerned the crest might come out to that arc; but the position of that from *d*, further in, shows that before the material could be filled out to the outer arc it would be over-running at *d*.

While the line *EFG* is the farthest limit to which the crest can be carried, it does not follow that the foot of the dump will run out to the property line at all points. For instance, with the material falling away at an equal angle on all sides, it is evident that *F* cannot be pushed out far enough to cover the extreme corner without over-running on both sides. A portion of the corner and also any high points, such as those opposite *E* and *G*, will remain uncovered. The outline of the base is obtained, as in Fig. 52, by measuring out a distance from the crest equal to that from the vertical in the auxiliary view to the intersection of the sloping side of the given level. Thus, to locate the point *e* on the 940-ft. contour, cut that contour with an arc swung from *F* with a radius equal to *m''n''*, etc.

The contour-levels on the side of the dump corresponding to those of the ground will be a series of equidistant lines, the distance between them being equal to the difference between the successive lines *m'n'*, *mn*, etc., in the auxiliary figure. Wherever the dump-contour and the ground-contour for the same level intersect there is a point on the outer edge or foot of the dump.

X. **Location of Ridge for Maximum Capacity.**—If it is desired to store a maximum tonnage on a given space the ore must rise from the boundary-line on all sides at the angle of rest of the material. If the ground is level the sides will meet in a point for a square or round area, in a straight horizontal ridge for a rectangular area, and in a straight, inclined ridge for an area bounded by non-parallel straight sides. When, however, the ground is broken and irregular, as is generally the case, the sloping sides will no longer be plane surfaces, and will meet in a sloping and irregular crest. It is an advantage to locate this crest in advance, for it is only when the material is deposited along this line that the maximum storage-capacity of the ground is utilized. This crest, then, would indicate the proper location for a dumping-trestle, for material can be filled in along this line until it begins to over-run on both sides at the same time.

Let it be desired to cover the tract shown in Fig. 54, from some point, such as *F*, on the upper side. Locate *F* and the course of a dumping-trestle from which the entire tract may be filled in. Use the auxiliary side-view as before and work in from the boundary-lines, the first radii being *mn*, as at *A*, *B*, *C*, the second *m′n′*, etc. Here every fifth line is used, and the intermediate ones are filled in only along the crest where they are needed. The construction used will be clear to one who has followed the previous two problems. A contour on the dump, starting from *C*, would pass *B* at a distance of *mn* away, and would pass *A* at a distance of *m′n′* away, etc. The dump-contours located from each side will be found to intersect along a broken line, *FHG*, which is the crest. This line is the theoretical course for a trestle and may be adhered to as closely as is deemed desirable. A slight spur would have to be run to the left from a little below *H* as far as *I* to fill in the left-hand corner completely, but the capacity gained would hardly justify the expense.

XI. **To Plot the Outcrop of a Vein, which May be Considered as a Plane Surface.**—Descriptive geometry methods may be used to determine the probable outcrop of a vein. First, let the vein be free from faults and foldings, and the strike and dip be known

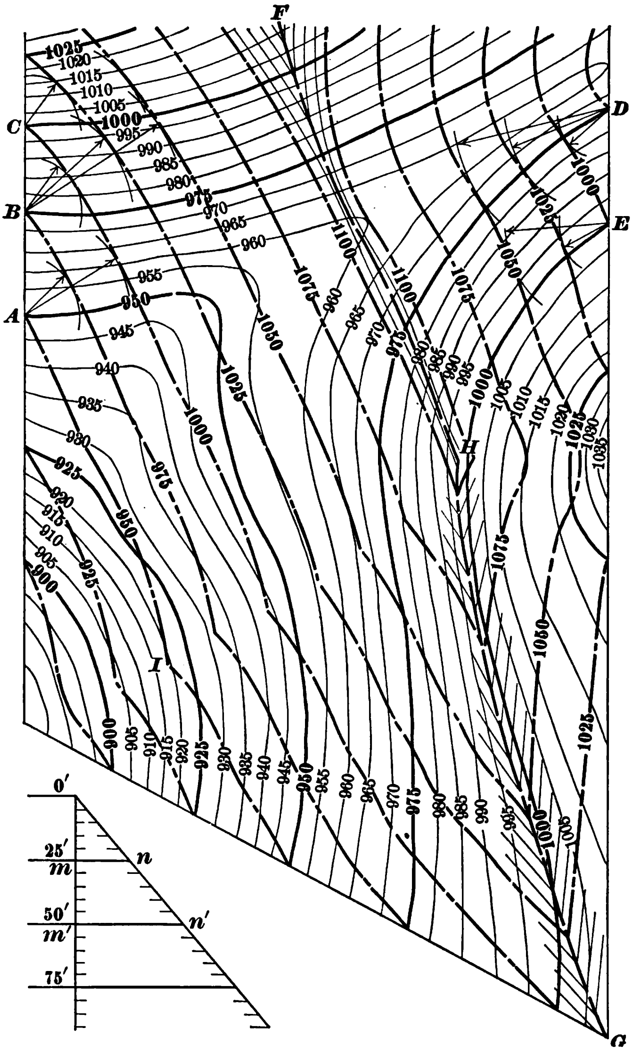

F
C
B
A
D
E
H
I
G
0′
25′
m
n
50′
m′
n′
75′

Fig. 54.

for some definite position, as *A* in Fig. 55. Draw an end-view looking up the strike-line. For convenience, let this end-view be drawn with the line *XX* through *A* perpendicular to the strike as the horizontal plane through *A*. Let the series of lines parallel to *XX* be the end-views of the horizontal planes corresponding to the contour-lines of the map. If a number of parallel planes be cut by a common secant plane, the resulting intersections

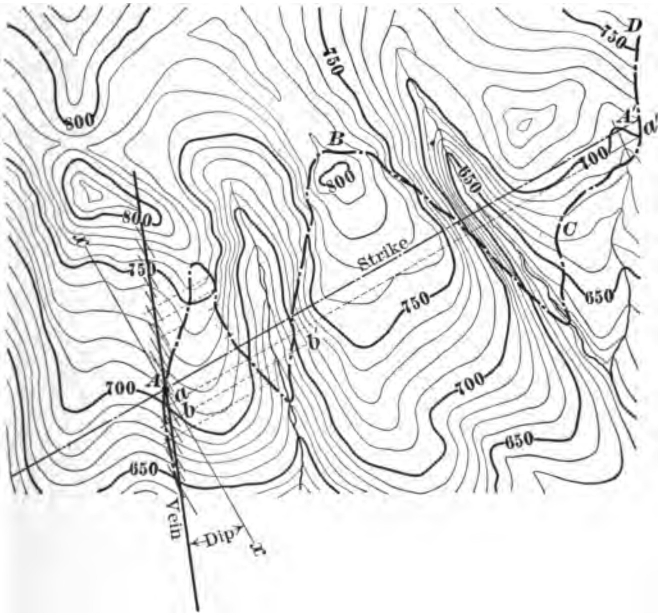


FIG. 55.

form a series of parallel lines. The lines *aa'*, *bb'*, etc., projected up from the intersection of the vein and the various levels, are in reality the contour-levels for the vein, which in this case become a series of parallel lines. Wherever, therefore, the line *AA'* and the 710-ft. surface-contour cross, we have a point in the vein and on the surface of the ground; that is, on the outcrop. Similarly, the intersections of the line *aa'* and the 700-ft. contour

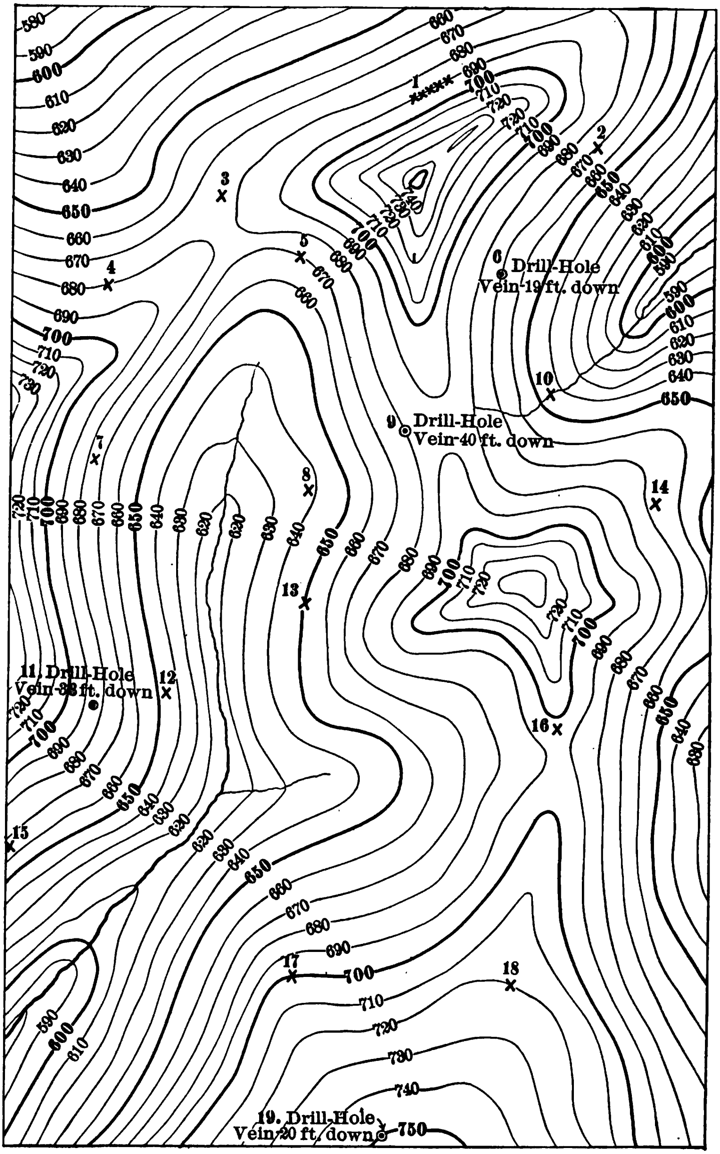

1
2
3
4
5
6 Drill-Hole
Vein 19 ft. down
7
8
9 Drill-Hole
Vein 40 ft. down
10
11 Drill-Hole
Vein 38 ft. down
12
13
14
15
16
17
18
19. Drill-Hole
Vein 20 ft. down
580
590
600
610
620
630
640
650
660
670
680
690
700
710
720
730
740
750

FIG. 56.

give points on the outcrop. By locating these intersections for each level and connecting them up we have the outcrop. This method can be used only for comparatively small areas where the vein may be considered as a plane surface. When the vein is faulted to any great extent the treatment becomes complicated, so much so as to preclude its consideration in this paper. When the vein is continuous but folded, as, for instance, a coal-seam, a method of determining the outcrop may be used, which is illustrated in Figs. 56 to 56b.

XII. **To Determine the Outcrop of a Folded Vein or Seam.**—Let Fig. 56 be a contour-map of an area on which an irregular outcrop has been partly located, as, for instance, at the stations marked with an *X*. At various other points, as 6, 9, 11, 19, drill-holes have been sunk and the seam located at the depths noted. The form of the folded seam may be determined if we can establish its contour-lines corresponding to those on the surface, and where these seam-contours intersect those of the surface of equal elevation we have points on the outcrop.

For the sake of clearness, we will gather all the information available into a separate illustration, Fig. 56a. This gives us stations 1 to 19, with the elevations of the surface of the seam for each, as noted. A general inspection shows that there is a syncline near the middle of the tract, the depression running NE-SW., since stations 8, 9, 10, 11, 12, 13 are all at nearly the same level. Assuming, for a start, that the dip from the higher points, as 16, 17, 18, etc., toward the depression is substantially constant, lines may be drawn connecting the stations, and the elevations at the contour intervals may be interpolated, as on lines 13–16 and 13–18. Where necessary the levels may be extrapolated, as on the extensions of lines 8–16 and 12–18, but points so located are, of course, not so reliable as the interpolations. They aid, however, in obtaining the general direction of the contours, and as the seam has been eroded at these points great accuracy is not needed.

In this way a series of points of equal elevation are obtained for both sides of the depression. The auxiliary lines, such as

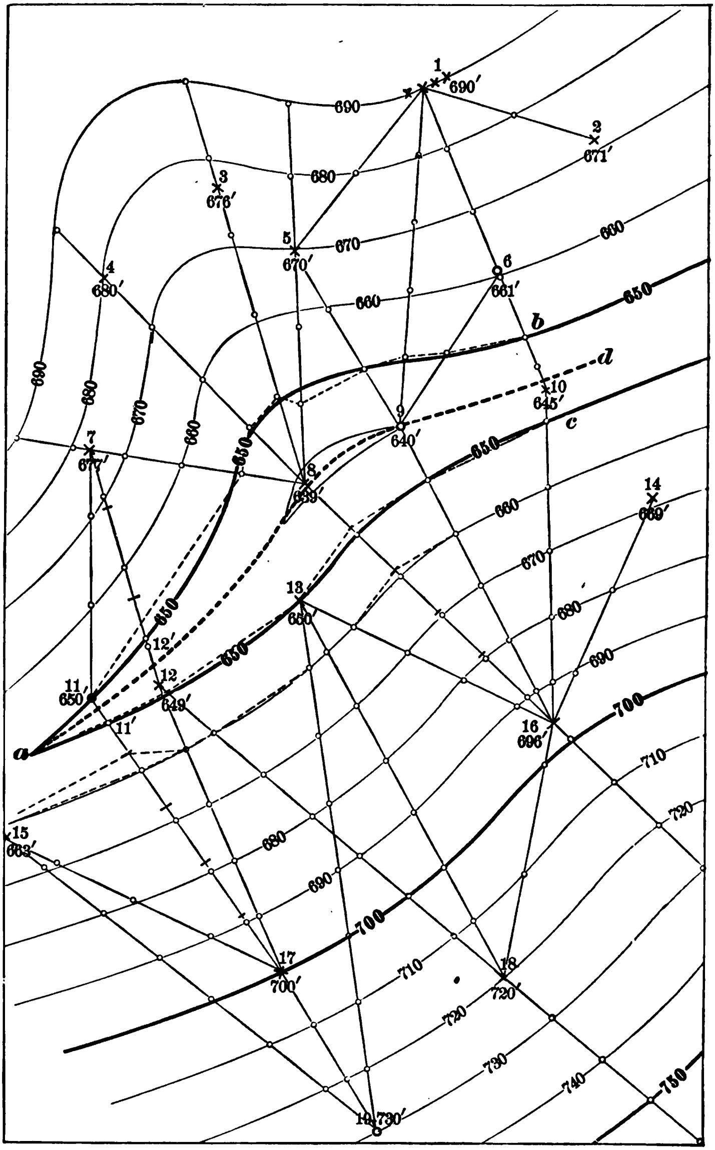

1
690′
2
671′
3
676′
4
680′
5
670′
6
661′
7
677′
8
639′
9
640′
10
645′
11
650
11′
12
649′
12′
13
650′
14
669′
15
663′
16
696′
17
700′
18
720′
19
730′
a
b
c
d
690
680
670
660
650
700
710
720
730
740
750

Fig. 56a.

12–18 and 9–16, which are substantially perpendicular to the depression, will be steeper, cross more contours, and give more reliable interpolations than lines more nearly parallel. In interpolating with these lines care should be used that they connect stations on the same side of the depression, as, for instance, 11–17. Station 12 is probably on the same side as 17, but 11 may be, and in fact is, on the other side. This may be determined as follows: The points on the 650- and 660-ft. levels line up well except those marked with a cross-bar on lines 11–17 and 7–12. Rejecting these two sets and connecting the others, we have the broken lines *ab* and *ac*, which give the general location of two 650-ft. contours. Assuming that the trough lies midway between these lines, we obtain the dotted line *ad* as its location. If now we take a new point, 11′, on the opposite side of *ad* and at the same distance from it, and interpolate the line 11′–17, we obtain points agreeing well with the others. In like manner, a new set of elevations may be obtained for the lines 7–12, 8–16, and 6–10.

Connecting the various points of equal elevation by curves, we obtain seam-contours, as shown in Fig. 56a. If these seam-contours of Fig. 56a be supermiposed on the surface-contours of Fig. 56, we will have a series of points where contours of equal elevation intersect, which will determine the irregular outcrops, *ABCD* and *EF* of Fig. 56b. The shaded portions indicate the areas under which the seam lies. Elsewhere it has weathered away. The probable depth of the seam at any point may be obtained by subtracting the elevation of the seam from that of the surface, as indicated by the respective contours for that point. For instance, at *G* the depth is 690 ft. less 655 ft., or 35 ft.

The value of this contour-method, where the outcrop is overgrown or obscured by soil, is obvious. An excellent example of its application will be found in the Masontown Folio of the U. S. Geological Survey, where structure-contours have been drawn on the upper surface of the Pittsburg coal-seam, showing its elevation above sea-level. Over large portions of this area the coal has been eroded. Where observations were obtainable

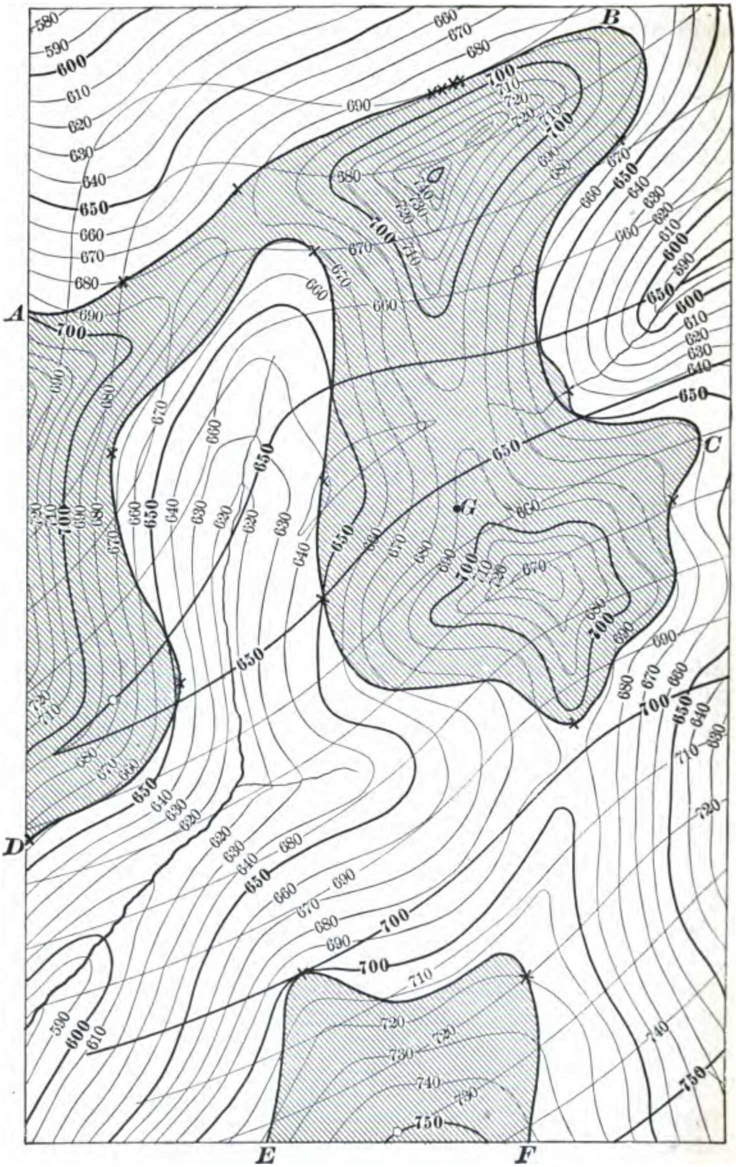

A
B
C
D
E
F
G
580
590
600
610
620
630
640
650
660
670
680
690
700
710
720
730
740
750

FIG. 56b.

a stratum was observed to maintain a substantially constant interval below. This lower stratum was but little eroded, and was used to obtain the theoretical position of the eroded portion of the coal-seam. A number of hills, high enough to pierce the seam thus located, were found to contain portions where its presence would not otherwise have been suspected. This indirect method of using parallel strata was also utilized where the seam lay too deep for observation direct, in this case the stratum being above the seam.

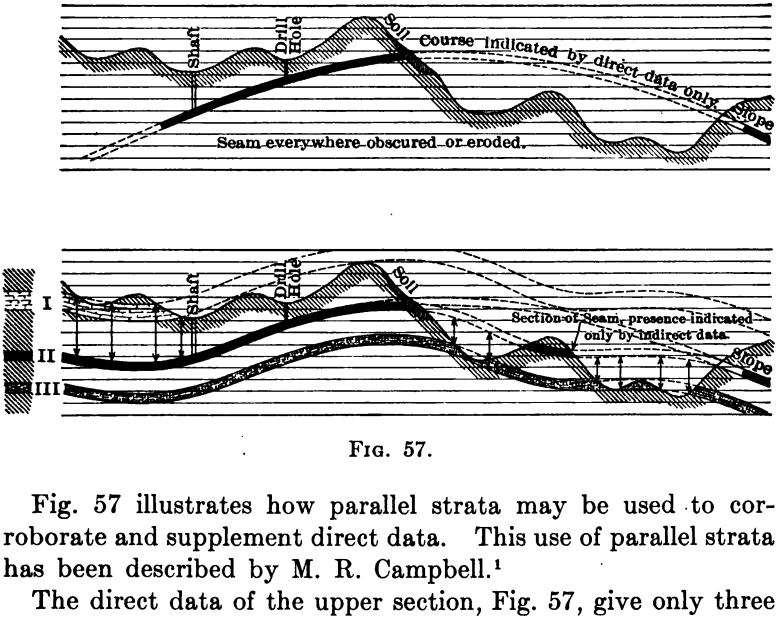

Shaft
Drill Hole
Soil
Course indicated by direct data only.
Slope
Seam everywhere obscured or eroded.
I
II
III
Shaft
Drill Hole
Soil
Section of Seam, presence indicated only by indirect data.
Slope

Fig. 57.

Fig. 57 illustrates how parallel strata may be used to corroborate and supplement direct data. This use of parallel strata has been described by M. R. Campbell.[1]

The direct data of the upper section, Fig. 57, give only three points on the seam, which is everywhere obscured or eroded. If the intervals between I. and II. and II. and III. in the columnar section be established, and if I. and III. be located at various outcrops, as shown in the lower section, then the intervals may be set off from these outcroppings, and will greatly increase our information on the surface to be contoured.

[1] Trans., XXVI., 298 (1896).

I wish to acknowledge my indebtedness to Prof. John D. Irving, who was engaged on the work of the Masontown quadrangle, and who suggested this structural contour-method as one of the useful applications of descriptive geometry to mining-work.

CHAPTER X

APPLICATION OF GEOLOGICAL THEORY

THEORIES OF ORE DEPOSITION

Early in the development of the science of geology investigators were concerned more with the broad general problems which engaged their attention upon every side. As these became cleared other fields were entered for more detailed study, and of these perhaps the most attractive is that of the occurrence and origin of ores. This is more especially the case since the search for the metals has continued since the earliest days of the race and has frequently been a powerful motive in the spread of civilization. And again the control of the sources of metallic wealth is recognized as one of the factors necessary to industrial supremacy.

The science of economic geology has therefore developed along practical lines and the geologist engaged in such work occupies the middle ground between the scientist and the practical man. Too frequently he is nearer the latter than the former; but from the work of the Government surveys and the various private surveys it has become quite apparent that the application of geological knowledge to mining problems is one of increasing importance. It would be impossible to take up all the phases of the matter in a book of this kind, but it may be well to point out the lines along which geological considerations may be of great value.

To do this it will first be necessary to review the present theories of ore deposition. In outlining the general principles of the origin of ore bodies it has been necessary to draw upon the beliefs of two more or less opposed schools of thought; naturally nothing strikingly new or profound is proposed, since the idea is rather to indicate the practical application of existing theories.

Generally speaking, geological history falls into two great groups of processes. Upon the one hand are the forces which tend to build up the land areas and on the other those which tend to erode or destroy them. The formation of ore bodies is a phase of natural activity attendant upon these general forces, and we therefore might expect to find it accompanying the action of those of both types. Thus the discussion falls naturally into two lines of thought each of which has been followed up closely by its adherents. Where there have been disturbances of the earth's outer mass resulting in folding, fracturing and the manifestation of volcanic action we have the chief instances of the upbuilding forces, and the association of ore deposits with areas which have been so affected, was noted by the earliest observers. More closely, regions where igneous rocks are abundant seem to be the more favored localities, and in the great majority of cases we find a relatively clear connection between ore bodies and igneous masses. It has further become apparent that the metals seem to be associated with the acidic and basic extremes of rock types.

Going further into the matter two questions are to be answered. Where did the metals come from? What was the transporting agency? It is upon these questions that the two lines of argument have been developed. In the igneous rocks we find such minerals as magnetite, ilmenite, pyrite, and other sulphides closely associated with the rock minerals and of the same age or period of crystallization. Metallic minerals sometimes segregate to such an extent as to form ore bodies. Hence the adherents of the "magmatic theory" hold that the igneous masses in the depths of the earth are the source of the ores. Both schools agree upon water as the great transporting agency and the supporters of the magmatic theory believe that the water is derived mainly from the same source as the ores, namely the "magmas" or solutions of rock minerals. In confirmation of this view they note the great clouds of steam observed in volcanic eruptions, and call attention to the fact that deep mining penetrates a dry zone. (Refer.: J. F. Kemp, Transactions A. I. M. E., Vol. XXXI —"The Rôle of the Igneous Rocks in the Formation of Veins.")

A rock magma may be regarded as a solution from which the rock-forming mineral compounds crystallize successively as their points of saturation are reached, under varying conditions of temperature and pressure. If such a solution were homogeneous at all stages of its cooling, we would expect to find rocks of the same type always resulting from its solidification. As a matter of fact this is not the case, since lavas of widely different character are derived from the same volcanic vent. This might be explained by assuming the existence of different reservoirs each contributing its particular rock type to the main vent, but it does not seem so reasonable in view of further facts. In the field within comparatively limited areas we sometimes find great variations in the rock which shade into each other by gradual stages; the extreme types would not be recognized as belonging to the same mass were it not for the field relations.

Thus the idea of magmatic "differentiation" or splitting up has been developed. How this takes place has been a subject for considerable speculation; some theorists have attributed it to differences in specific gravity of the component elements, or differences resulting from partial solidification of the molten mass in the great subterranean reservoirs. Convection currents and molecular flow have been supposed to play a large part in this arrangement of the rock material. Again it has been suggested that the behavior of a rock magma is analogous to the formation of a complex alloy. (Refer.: T. T. Read, *Economic Geology*, Vol. I, No. 2—"The Phase Rule and Conceptions of Igneous Magmas; Their Bearing on Ore Deposition.")

However this may be, the chief things to bear in mind are that there are successive stages in crystallization, and that toward the end of the process certain elements or minerals may be found in excess of the requirements for the rock of the solidified mass. Associated with this residual material we would expect to find the more volatile compounds—much water vapor, chlorine, fluorine, sulphur, arsenic, antimony, and telluride compounds. This would seem to be especially true as far as the lighter, more acidic rocks are concerned, and of the rock forming minerals, quartz, orthoclase, etc., would be most likely to occur as end products of the differentiation. They are actually represented as such in the form of pegmatitic dikes or veins which frequently carry metallic minerals in small amounts. Sometimes due to a change of physical conditions the residual quartz may subsequently be forced into the solidified rock mass and resorb or silicify it. With the failure of orthoclase in the residual material or " rock juice," there results a quartz which is the connecting link between the pegmatite dikes and the true vein quartz; so that there will be dikes of quartz with a few scattered feldspars, changing into dikes or veins showing quartz and no feldspars at all. But water vapor and other more volatile compounds migrate further before deposition begins forming the metalliferous veins of the familiar type; so that the pegmatite veins form one end of a series of vein stages which range from igneous or magmatic conditions to surface deposits. Pegmatite veins are known to carry gold and other ore minerals in small amounts; assays have also shown values of gold in the pegmatitic quartz dikes mentioned above. These dikes seem to belong to about the same stage as the quartz which frequently characterizes contact zones.

Writers upon this subject of vein stages or zones (Refer.: Waldemar Lindgren, *Economic Geology*, Vol. II, No. 2, page 105—"The Relation of Ore Deposition to Physical Conditions." Also J. E. Spurr, same, Vol. II, No. 8, page 781—" A Theory of Ore Deposition." Also W. H. Emmons, same, Vol. III, page 611—" A Genetic Classification of Minerals") have classified the various minerals in successive zones. The following description is based largely on their work:

1. The zone of igneous conditions, where the minerals have crystallized out of a molten magma. Examples of this zone with especial reference to ore minerals, are the deposits of magnetite in the Adirondacks, and the chalcopyrite and nickeliferous pyrrhotites of the Sudbury District, Ontario, which represent segre-

gations in igneous rocks. Belonging to the same zone but of somewhat different type, are the disseminations of cupriferous pyrite and chalcopyrite in the granites or granite porphyries.

2. The zone of pegmatites. Example: pegmatitic veins containing tin, such as those of Cornwall. The coarse veins of quartz, feldspar, and mica, frequently found in large granite masses, belong here also.

3. The zone of contact metamorphism. Examples: Ore bodies at the contact of different intrusive rocks and limestone such as are found at Cananea, Sonora; and Velardena, Durango, Mexico. (Ref.: S. F. Emmons, *Economic Geology,* Vol. V, page 335—"The Cananea Mining District of Sonora, Mexico." J. E. Spurr and G. H. Garey, same, Vol. III, page 687—"Ore Deposits of the Velardena District, Mexico.")

4. The deep vein zone. Veins, of this class formed at great depth under high pressure and temperature. They carry gold chiefly and are typified by the veins in the pre-Cambrian formations of the southern Appalachians, and the veins of the Mother Lode group in California.

5. The lower vein zone, typically the cupriferous pyrite or copper zone. The copper veins of Butte, Montana, are typical of this zone though there is clearly a transition to the upper zones. Some of the Arizona deposits such as those at Bisbee also show this stage.

6. The lower middle vein zone, typically the galena-blende zone. The lead deposits of Colorado fall mostly into this class.

7. The upper middle vein zone, characterized by the presence of gold and silver in the more volatile compounds. The "bonanza" veins found in Nevada and Old Mexico belong to this stage which was also well represented in the Smuggler Mine, at Aspen, Colorado.

8. The upper vein zone, chiefly barren quartz and calcite veins formed under conditions approaching those of the hot spring type.

The distribution of minerals with respect to these zones is shown in the table of Fig. 58, which is based chiefly on the one

ORIGINAL VEIN-FORMING MINERALS

● Characteristic of the zone. ○ May occur in the zone. ○? Occurrence questionable

	Minerals	Zone of igneous conditions	Zone of pegmatites	Zone of contact metamorphism	Deep vein zone (gold)	Lower vein zone (copper)	Lower middle vein zone (blende, galena)	Upper middle vein zone (silver-gold)	Upper vein zone
	Ilmenite	●	○?	○	○	○			
(Titaniferous)	Magnetite	●	○	○	○	○			
	Chromite	●							
	Corundum	●	○	○					
(Nickeliferous)	Pyrrhotite	●	○?	○	●	○			
	Molybdenite		●	○	○	○	○	○	
	Cassiterite	○	●	○?	○?				
(Cupriferous)	Pyrite	○	○	○	●	●	○	○	○
	Chalcopyrite	○	○	○	○	●	○	○	
	Arsenopyrite		○	○	○	●	○	○	
	Zincblende		○?	○	○	○	●	○	
	Bornite		○	○	○	●	○	○	
	Gold	○	○	○	○	○	○	●	
	Specularite	○	○	●	○	○?			
	Quartz	○	○	○	○	○	○	○	
	Calcite			○	○	○	○	○	○
	Fluorite	○	●	●	○	○	○	○	○
	Rutile	○	○	○	○	○	○	○	
	Epidote			●	●				
	Muscovite	○	○	○	○	○			
	Sericite				○	○	●	○	
	Spinel	○	○	○	○				
	Orthoclase	●	●	○					
	Albite	●	○	○	○				
	Anorthite	●	○	○					
	Garnet	○	○	●	○	○?			
	Vesuvianite			●					
	Wollastonite			●					
	Diopside	○	○	●	○				
	Tremolite			●	○				
	Ilvaite			●					
	Staurolite			●					
	Andalusite		○	●					
	Pyroxene	●	○	○					
	Hornblende	●	○	○	○				
	Tourmaline	○	●	○	●				
	Characteristics of associated igneous rocks.	Acidic and basic rocks of granitoid texture.	Rocks chiefly of more acidic types. Pegmatitic and aplitic phases are common. Textures medium to coarse granitoid, rocks often schistose or gneissoid.			Texture medium granitoid to coarsely porphyritic.	Texture medium porphyritic. Typical porphyrics.	Texture finely porphyritic surface flow.	

FIG. 58.

ORIGINAL VEIN-FORMING MINERALS—*Continued*

Minerals	**Zone of igneous conditions**	**Zone of pegmatites**	**Zone of contact metamorphism**	**Deep vein zone (gold)**	**Lower vein zone (copper)**	**Lower middle vein zone (blende, galena)**	**Upper middle vein zone (silver-gold)**	**Upper vein zone**
Topaz	○	●	○	○				
Scapolite		○	●	○				
Titanite	○	○	○					
Apatite	○	●	○	○	○			
Galena			○	○	○	●	○	
Cinnabar					○	○	●	○
Marcasite						○	●	○
Tetrahedrite					○	●	○	
Pyrargyrite							●	
Stephanite							●	
Polybasite?							●	
Argentite							●	
Stibnite							●	○
Silver						○	●	
Tellurides					○	●	○	
Chalcocite?					○	○	○	
Barite					○	○	○	○
Dolomite					○	○	○	
Siderite					○	○	○	
Celestite						○	○	○
Chlorite				○	○	○	○	
Adularia						○	○	
Opal							○	●
Chalcedony							○	●
		Rocks chiefly of more acidic types.						
Characteristics of associated igneous rocks	**Acidic and basic rocks of granitoid texture.**	**Pegmatitic and aplitic phases are common. Textures medium to coarse granitoid, rocks often schistose or gneissoid.**			Texture medium granitoid to coarsely porphyritic.	Texture medium porphyritic. Typical porphyries.	Texture finely porphyritic surface flows.	

FIG. 58.—*Continued*

given by Lindgren in the paper referred to above; a very comprehensive classification of minerals is also given in Emmons' paper to which reference was made. The table here is compiled from those mentioned, though the arrangement in zones is somewhat different; it may be that considering the present state of our knowledge of the subject, there are too many zones given, but it seems probable that some such scheme can be carried out satisfactorily as additional facts are reported which will permit of a more definite classification of the minerals into the divisions here outlined. In the table the more characteristic occurrences are noted by the black dots.

So much for the present day theory of ore deposition from the "magmatic waters" standpoint. Other geologists are of the opinion that descending surface waters have played the major part in the formation of ore deposits. The surface waters, charged with oxygen, carbon dioxide, and organic acids, pass through the fractured rocks, leaching them of their mineral content; they become heated as they attain depth, pass into trunk channels of circulation, and, as they cool upon again approaching the surface, deposit the minerals in the concentrated form of ore bodies. As was mentioned earlier in the chapter, there is some doubt as to whether "ground waters" ever attain the great depths assumed by the supporters of this theory.

However, recalling the idea of the building and erosion processes of geologic evolution, it seems that the truth must lie to some extent in both views. Cases of metallic mineral dissemination in the igneous rocks must be due to primary mineralization; with such a convenient source at hand as the heated magma itself for the origin of the transporting solutions, it seems a mistake not to regard this idea as the most logical one to account for the deep waters.

On the other hand it is certain that surface waters do erode vein deposits and bring about enrichment; and it is quite conceivable that they also dissolve and collect a portion of any disseminated metallic content in either the igneous or sedimentary rocks through which they pass, to deposit it later on under favoring conditions. That this may be the case is proved rather conclusively by the very complete leaching of the capping or "overburden" of the disseminated copper deposits in schist and porphyry, which have recently come into prominence in the Southwest. There leaching has in some cases been almost complete and the re-deposition has frequently taken place (Fig. 59) as small stringers rather than a true "dissemination." It is conceivable that under favorable conditions the concentration might take place in a main fracture so as to produce a vein owing its origin largely if not entirely to the action of surface waters.

Turning from the outline of the theories of ore deposition to the application of them, we enter a very interesting field. In the first place there are certain general considerations which are treated in the chapter on prospecting. Some of the more detailed considerations involved in the study of ore deposits may be treated as a series of rather generalized cases.

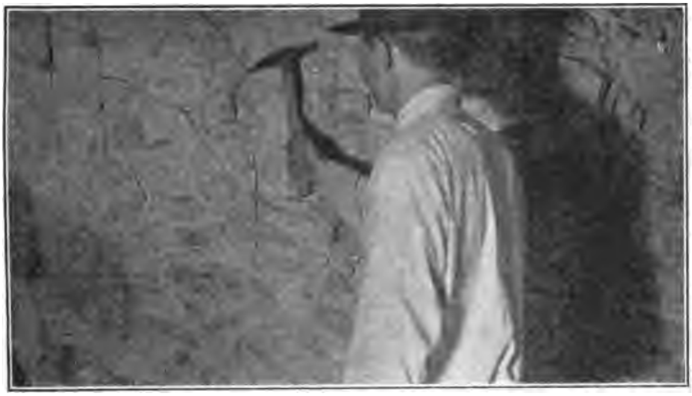


FIG. 59.—Chalcocite stringers in schist, believed to be "secondary" in character.

1. The ore body, in an igneous rock, consists of sulphides, having as a gangue the typical rock minerals. In basic rocks, look for segregations of sufficient importance to make workable ore bodies. In the acidic rocks, granites, and granite porphyries look for impregnation general enough to make a large low-grade ore body. Such an ore body would probably be of no economic importance at present unless subjected to secondary enrichment (see page 139).

2. A vein showing the minerals characteristic of pegmatitic conditions, giving assays for gold; from general theoretical con-

siderations it seems unlikely that such a vein will show any increase of values with depth due to changing primary mineral content, or to enrichment. It should be regarded with great conservatism, bearing in mind the formation of placers from low-grade gold veins. Pegmatitic veins are, however, the source of cassiterite or tinstone, and may become important either for the original content or the placers which have been formed from them.

3. A contact metamorphic deposit between limestone and diorite porphyry. The limestone is silicified and shows minerals of zone 3 of the table. Characteristically are found hornblende, garnet, vesuvianite, chalcopyrite, and galena. Since this is recognized as one of the lower vein zones it would not be expected to change greatly in depth. Without good evidence of enrichment such a deposit should be prospected carefully with close sampling. Deposits of this class sometimes offer possibilities as large low-grade smelting propositions, in view of the limey character of the gangue. The question of contact metamorphism is treated in more detail in Chapter XI.

Before going further with the discussion of the general cases it may be well to emphasize the fact that various stages of deposition are encountered often within a limited portion of an ore body; and that on the other hand not all of the stages may be encountered in any particular deposit. If it be supposed that the heat derived from an igneous mass has been a large factor in lending activity to mineral-bearing solutions, the ideal theoretical condition would be that of quick cooling with the hot solutions emanating during a relatively short period. Then we would expect to find the vertical range of different stages more or less well defined. But as a matter of fact the temperature of intrusives in large masses falls slowly, and as a result the stages overlap, and any given portion of a vein may lie first in the zone where the solutions are hot and under great pressure later as the heat center retreats, the upper zones tend to migrate downward. Thus the vein walls may show pyrite and chalcopyrite, and perhaps blende, associated with quartz, fluorite and garnet.

Next will be a band of galena chiefly, and blende, with siderite, barite, and quartz; a third stage may be represented by gold, quartz, and calcite; and finally there will be a barren calcite stage. These conditions might be represented diagramatically as shown in Fig. 60. The tendency is for the upper stages to work downward overlapping and cutting the earlier ones.

This process would be reversed if the heat center were rising instead of sinking, as might be the case if an intrusive mass were slowly penetrating overlying strata. This is believed to have been the case at Aspen, Colorado, where the normally earlier vein stages cut those which are usually characteristic of later periods. (Refer.: J. E. Spurr, Monograph 31, U. S. Geological Survey, and *Economic Geology*, Vol. IV, No. 4—"Ore Deposition at Aspen, Colorado.")

4. In this case the ore is argentiferous galena and gold quartz gangue chiefly; on the lower levels of the mine gold values are smaller and more scattered, there are galena and blende, with some pyrite and chalcopyrite. The inference is that the deposit is passing from the middle vein zones to the lower zone and will probably be less valuable.

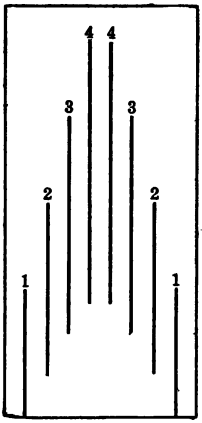


FIG. 60.—Diagrammatic illustration of overlapping vein stages.

5. The richer ore is chiefly tetrahedrite, pyrargyrite, and polybasite; lower grade material is galena and blende, gangue is quartz, barite, and calcite. It is probable that the deposit is in the upper middle vein zone, and that with depth the rich sulphides will give way more and more to galena and blende or chalcopyrite and bornite.

The various cases outlined above are simply intended to give the general idea of the application of the theory to possible cases. In practice, of course, an infinite number of variations may arise and it is impossible to lay down a set of definite rules to govern the judgement of ore bodies. However, enough has been said to emphasize the importance of studying carefully the vein history, the zones represented, their relations, and relative importance.

One point that should be noted in this connection is that the presence of the upper or barren vein zone should not be taken as indicating that the other zones will necessarily be encountered with depth. The possibility of overlap of the zones is so great that it would be rare not to discover some traces of the productive types. It is also probable that the gangue minerals of this horizon could be derived from a magma originally poor in its content of the metals; therefore, unless there is some good reason for it such outcrops should be let alone. Where the productive veins of a district are known to show the barren stage strongly developed in their upper portions it is possible that apparently barren veins occurring in the higher regions of a range of hills may be the surface representatives of lower productive stages, but it is usually possible to find confirmatory evidence. It should be remembered in this connection that such veins, even if they develop values below, may not offer favorable conditions for secondary enrichment.

CHAPTER XI

APPLICATION OF GEOLOGICAL THEORY—SECONDARY ENRICHMENT

Everyone is more or less familiar with the ideas of oxidation and enrichment. An ore body consisting of sulphide ores has been exposed to the action of atmospheric agents and the oxidizing and transporting action of waters carrying carbon dioxide, organic acids, and acids derived from the oxidation of the sulphides themselves, such as sulphuric acid. The oxidized products go into solution and are carried downward to be precipitated under the influence of the "primary," or unchanged sulphides, increase of pressure, etc. It may be that the outcrop will show oxidized ore minerals, or that it may be entirely leached. The descending solutions carrying a heavy metallic content, encounter the primary sulphides and from the reactions ensuing results the formation of other sulphides richer in the metals. At the ground water level, where the surface waters accumulate and remain comparatively stationary, the enrichment products are concentrated; since there is little circulation below the ground water level the sulphides of that region are not so much subject to change and will probably be low-grade.

The term "primary sulphides" refers to those which exist in the condition in which they were first deposited, presumably from hot solutions emanating from some region of igneous activity.

"Secondary sulphides" are those which have resulted from changes in the primary sulphides due to the enriching action of descending surface waters.

"Secondary sulphide enrichment" is the change from primary to secondary sulphides.

It is apparent that several factors may have a bearing upon secondary enrichment. These are (1) topography of the region;

(2) rainfall; (3) geological structure of the area; (4) character of the oxidizing waters; (5) solubility of the compounds forming the ores. Some of these effects are tabulated in Fig. 61. (Refer.: J. E. Spurr, "Geology Applied to Mining," page 274.)

Topography	Rainfall	
	Slight, region arid	Moderate to considerable
Surface is comparatively flat, slopes are gentle.	Erosion slow, ground-water level deep, outcrop thoroughly leached, oxidation passes to considerable depth.	Oxidation relatively complete, outcrop may show values, or they may have concentrated below. Outcrop will probably be well stained, oxide zone of moderate depth.
Surface is rugged, steep slopes.	Erosion rapid, waters pass off in run-off, sulphides prabably exposed at surface, oxidation patchy, but may be deep.	Ground-water level high, sulphides exposed on surface, may be no oxide zone.

FIG. 61.

The geological structure of the area may be of considerable moment in this matter. If the country rock is impervious, downward migration of the surface waters will be slow, or confined to the principal fractures; but if there is general shattering the enrichment will be more uniform. Again, underground conditions may be of paramount importance; troughs defined by impervious beds, or kaolinized dikes may create conditions favorable to the impounding of descending solutions. On the other hand, lines of easy underground circulation may be as unfavorable to concentration as conditions which favor excessive run-off of the waters on surface.

The solvent action of the descending waters is of importance; in the case of waters containing oxygen and carbon dioxide this is generally recognized, but there is still much chance for investigation. Comparatively recently W. H. Emmons pointed out the importance of manganese in furthering the solution of gold. (Refer.: W. H. Emmons, Transactions of the American Institute of Mining Engineers, 1910—"The Agency of Manganese in the Superficial Alteration and Secondary Enrichment of Gold-Deposits in the United States.") The relative solubility of the ore minerals should also be considered. Gold, for instance, would probably be affected only by some particular solvent as in the case just mentioned, and therefore the influence of the processes of secondary enrichment would ordinarily be small.

As regards the depth of the oxidized and enriched zone, it should be remembered that the ground-water level is usually the controlling factor but not always. In very dry regions there is practically no fixed water level; there are also cases where the water table has been raised or lowered by changes of climate, drainage, land elevation, or depression. Glaciated regions have usually been stripped of the weathered surface material and sulphides are exposed on the outcrop.

The oxidized zone may be recognized by the following characteristics:

1. The absence of water in the mine workings (except during periods of heavy rainfall).
2. The weathering and cracking of the country rock.
3. Extensive leaching, which may have impoverished the ore bodies in the upper portions.
4. The presence of the following minerals (Refer.: Waldemar Lindgren, *Economic Geology*, Vol. II, No. 2, page 124—"The Relation of Ore Deposition to Physical Conditions"):

Opal
Kaolin
Limonite
Pyrolusite
Psilomelane
Hematite
Cuprite
Smithsonite
Calamine
Anglesite
Pyromorphite
Celestite
Malachite
Chrysocolla
Chalcanthite
Cerargyrite
Alum
Alunite.

Gold, copper, and silver also occur in the native state, but are not characteristic.

5. Casts and pseudomorphs of earlier minerals.

6. Cores of original sulphides coated with the carbonates, sulphates, etc.

The zone of secondary sulphide enrichment may be recognized by the following characteristics (Refer.: F. L. Ransome, *Economic Geology*, Vol. V, No. 3, page 205—"The Criteria of Downward Sulphide Enrichment." Also discussions of this paper in succeeding issues):

1. Variations in value of the ore which may take these forms:

a. A sudden increase after passing through a leached or impoverished zone, showing abundant signs of oxidation.

b. A sudden decrease upon passing below a certain horizon (marking the transition to the lean sulphides).

c. In deposits where the limits are not so sharply defined, a general tendency toward decreasing values with depth may be indicative of enrichment of the upper zones.

2. The following minerals (Refer.: Lindgrens paper above noted) (The minerals particularly characteristic are in italics):

Quartz
Chalcedony
Opal
Kaolin
Gold
Silver
Pyrite
Galena
Chalcopyrite
Bornite

Covellite
Chalcocite
Argentite
Pyrargite
Stephanite
Polybasite
And other sulpharsenites and sulphantimonites.

3. The presence of residual cores coated by secondary minerals.

It seems quite evident from the foregoing that we are dealing with considerations of a more or less theoretical nature coupled with the knowledge of observed characteristics, and that the deduction to be drawn from the whole may be of great value in practice.

Some Possible Cases.—1. In a region of little rainfall with quite rugged hills small outcrops are encountered showing mixed sulphide and oxide minerals; oxides of iron and manganese, some galena, and red and yellow powdery material upon breaking the specimens. The inference is that the small croppings are due to erosion which is relatively rapid as a result of the steep slopes; that the ore bodies will have pockets of oxidized material to some depth, and that for this reason may show values much higher locally than the general average of the deposit.

2. In this same locality but down toward the plains, an area is found showing a basin-like structure, signs of extensive shattering and leaching, and alteration of the rocks; there are casts of pyrite, but not much iron staining on the surface. There is a possibility that there has been a general "disseminated" mineralization, and that the surface zone has been thoroughly leached. The slight rainfall and the presumably deep level of the ground water do not seem favorable for concentration and enrichment of the deposit.

3. The country rock is much shattered over wide areas and has been altered and mineralized along numerous small fractures; there is noticeable staining of the outcrop and the casts of pyrite are quite abundant. The region is one of moderate rainfall and there is evidence of considerable erosion; the ground-water level has been proved to exist at no great depth. This occurrence is more promising than that of the previous case because of the evidences of more erosion and the probability of concentration in a relatively shallow zone.

4. A well-defined vein showing strong iron stained cropping in a region of moderate rainfall; the slopes are quite steep. Values are low on the outcrop. The probability is that there has been erosion sufficient to produce extensive concentration, provided the original minerals were soluble, if so the enriched zone should be encountered at no great depth.

5. The area is quite rugged and there is abundant rainfall; the outcrop shows sulphide minerals little altered, and the assays

are low. The inference is that the lean sulphide zone is exposed and that no enrichment may be expected.

6. Ore bodies have been mined consisting of lead and zinc carbonates, with some azurite and malachite, lower down galena and blende form the bulk of the ore with coatings of the carbonates, the workings are beginning to be wet. The conclusion is that the bottom of the oxidized zone is being approached, the sulphides will form the ore at greater depth and that the values will decrease.

7. This case is that of a copper mine where they mined large bodies of azurite, malachite, and the black oxide of copper; then passed into a zone of cuprite, chalcocite, and bornite, in which large stopes were mined. The bottom of the shaft three hundred feet below encountered abundant flow of water so that work on that level was abandoned for the time being. It is probable that the limit of the enriched zone is near; ore bodies below the water level will probably be "spotty" among fracture lines. It would perhaps be best to carry on development by means of winzes in the ore to determine as soon as possible the character of the primary ores.

An endless variety of cases might be outlined; in fact, it would be possible to cite numerous examples from ore bodies that have already been mined. But given an understanding of the theory involved, and sufficient knowledge to recognize the things which may be encountered in the field, it is possible to predict to some extent what the most probable outcome will be in a given case; it does not do to forget, however, that some fact not easy to determine and take into consideration may upset the most elaborate theory concerning an ore body, and after all there are still many things that are far from being thoroughly understood about such matters.

Contact Metamorphism.—"Contact metamorphism" is the general term applied to those changes and conditions which are characteristic of the contacts between sedimentary rocks and intruding igneous bodies.

The earlier idea of the process was that the changes are due largely to the recrystallization of mineral-forming compounds in the intruded sedimentary rocks; so that the argillaceous limestones for instance, were supposed to offer the most favorable material for the development of the "contact" minerals; in the field, however, we find that the development of these minerals does not take place uniformly along a boundary. The changes are sometimes intimately connected with lines of easiest penetration, such as bedding planes; again the minerals may occur as veins in the intruded rock. An examination of sets of analyses also brought out the fact that the unaltered rocks (limestones) near such contact zones do not carry the amounts of the elements necessary to produce the typical minerals. (Refer.: J. F. Kemp, *Economic Geology*, Vol. II, page 1.—"Ore Deposits at the Contacts of Intrusive Rocks and Limestones; and Their Significance as Regards the General Formation of Veins") Further it has been found that the typical contact minerals are developed in many instances in the igneous mass near, or even some distance from the contact. As an instance of this J. E. Spurr and G. H. Garrey say: (Refer. J. E. Spurr and G. H. Garrey, *Economic Geology*, Vol. III, page 710—"Ore Deposits of the Velardena District, Mexico") "In many cases a greater amount of limestone is more altered than of the intrusives; in others the results are about equal; and in important examples far more of the igneous rock than of the limestone has been completely metamorphosed."

The conclusion is that the changes are due to replacement of and addition to the original rock minerals consequent upon the activity of the solutions which form the end products of magmatic differentiation; possibly a term more descriptive of this process would be "aqueo-igneous metamorphism."

Sandstones do not show any very marked changes of composition due to contact metamorphism; shales furnish many well-known examples; but the cases which are of by far the greatest importance from a practical standpoint are those of limestones in contact with various igneous rocks. This is due to the fact that limestones are very widespread in occurrence, that they form thick beds, and that the rock yields more readily to solution and replacement and is generally more pervious than the argillaceous sediments. The fact that the active solutions are siliceous may also be a factor worthy of consideration.

In examining a typical contact zone passing from the igneous to the sedimentary side, it is first noticed that the rock minerals become less easily distinguished and the texture is more compact. Patches of siliceous material begin to develop, perhaps enclosing cores of unaltered rock. The next stage is more complete silicification, the "contact minerals" become recognizable, and the original nature of the rock is entirely obscured. Usually the original line of the contact cannot be traced. Passing to the limestone side of the contact the iron, magnanese and aluminium silicates, while they still may occur, give way to the calcium and magnesium silicates; limestone shows as residual patches, possibly highly crystalline. The dark silicates, such as garnet, horneblende, vesuvianite, etc., become less and less noticeable and the prevalent minerals are the lighter colored ones such as tremolite, diopside, wollastonite, etc. These may be found at considerable distance from the contact, gradually merging into the characteristic bands of silicified limestone.

As to the ore minerals, they seem to be associated most closely with the minerals more typical of the immediate contact, notably garnet. Fig. 62 is a tabulation which will serve as a convenient summary for the general associations; the division into stages is very rough but may serve as a basis for further observation and elaboration as more facts are acquired.

The application of these ideas regarding contact metamorphism must be worked out carefully for each occurrence in the field and there would be some danger in trying to lay down exact rules to control it. In general, however, we may infer that when we encounter such cases without evidence of the later vein stages, we have to do with ore bodies that were formed at depth and under pressure not favorable to the occurrence of the richer ore minerals, and we would not expect any notable concentration of values in such primary ore bodies. As has been previously mentioned, therefore, enrichment is a necessary factor in most cases to give deposits of economic importance; there are instances, however, where ore bodies of this type showing little or no enrichment have been mined. Where the minerals characteristic of the earlier stage predominate, without traces, at least, of the sulphides we may be justified in concluding that the later productive stage occurred in a higher zone than the one exposed by the present contact and that it has been removed by erosion. It frequently happens that belts of silicified limestone showing the minerals of the later barren stage, are prospected to some extent, but it would seem that such work is hardly justifiable, since the chances of finding anything of importance are small.

OCCURRENCE OF COMMONER CONTACT METAMORPHIC MINERALS

Minerals	Earlier barren stage	Productive stage	Later barren stage
Magnetite	●	○	
Specularite	●	○	
Pyrite	○	●	
Arsenopyrite		●	
Zincblende		●	
Galena		●	
Bornite		●	
Fluorite	○	●	
Garnet	○	●	
Vesuvianite	○	●	
Hornblende	●	○	
Augite	●	○	
Diopside	●	○	○
Wollastonite			●
Quartz	○	○	●
Calcic feldspar	●		
Calcite			●

○ known to occur in the stage.
● More characteristic of the stage.

Fig. 62.

The Significance of Rock Texture.—In the earlier days it was thought that the differences in rock texture were due to the different ages of the formations. For instance, in the Laurentian, or Archean, period it was formerly thought that granites were formed, while volcanic flows were supposed to be characteristic of the later periods. This was assumed because the older land areas do show great granite masses which are easily recognized; they also show other formations in which gneissoid or schistose structure has obliterated the original characteristics of the rock, in consequence there has been much speculation as to origin. It was some time, consequently, before we realized that these metamorphosed types might have originally been similar to the flows of later age. As more has been learned about rocks it has been realized that age has nothing to do with rock texture except in-so-far as it may have controlled the conditions of temperature and pressure due to overlying formations. In other words, an old rock is more likely to have been covered by later sediments than a younger one.

It is now thought that the chief factor controlling the texture of igneous rocks is the depth at which they are formed; this determines the pressure, the temperature, and the rate of cooling. Thus we know that volcanic flows poured out upon the surface of the earth cool quickly, giving amygdaloidal and glassy textures. Rocks that cool slowly in the depths of the earth assume a coarsely crystalline or granitoid texture. The various gradations between these two extremes have been grouped under the "porphyritic" textures (see page 152).

Working in the other direction, then, we can tell from the texture of a rock something about the conditions under which it was formed. For example, a rock of glassy texture we at once assume comes either from the margin of a surface flow or the margin of a dike, chilled rapidly by contact with cold walls. Vesicular or amygdaloidal texture we take to indicate that the rock was poured out as a flow upon the surface of the earth.

If we have some question involving the possible extent of a formation, and can prove it to be a flow, we can give a fairly intelligent answer. It may be possible to tell when a dike has been encountered in underground workings by the gradations of texture. For instance, suppose a crosscut is being driven in an igneous mass and the question arises as to whether it is simply a dike, or a more extensive mass. The texture on the edge may be glassy, giving way to finely crystalline material, while further along the texture may be coarsely porphyritic. If the next change is to a finer texture again it may be assumed that the other side of the dike is being approached. Bodies which show uniformly coarse granitoid texture are usually quite extensive and it may not be advisable to explore them to find what is on the other side.

In a previous chapter it has been pointed out that the character of an ore body changes with depth and the consequent variation of conditions. It might be expected, therefore, that there will be some slight parallel between the nature of an ore body and that of an igneous rock forming the wall. This is true in a general way, as indicated in the table on page 132. We see that the deeper vein zones are associated with the coarsely granitoid rocks, the middle zones with the corresponding transitional textures, while the upper zones are often found in flows.

Finally we may tell something about the stage of an intrusion —whether it was in the earlier or later period of its action. Since marginal chilling underground depends upon the coldness of the country rock, it is clear that if large quantities of heated material have already passed a certain part of the wall rock, the latter will be heated and cease to exercise a chilling effect upon the intrusive. When we find that a dike does not show any marginal phases, we are led to infer that the later part of the intrusive period is represented.

From the descriptions of this chapter it will be evident that the interest attached to reading a geological report rests quite as much upon the reasons for the conclusions reached as it does upon the conclusions themselves; and it seems that if writers would be more careful sometimes in stating their reasons for certain deductions, there would not be so much doubt as to the validity of the opinion expressed.

CHAPTER XII

ROCK CLASSIFICATION

"A rock may best be defined as any mineral or aggregate of minerals that forms an essential part of the earth."—Kemp.

According to this definition a rock may be made up of a single mineral or many different ones, but it must be a quite extensive formation, distinguishing it from the ore deposits, which do not as a rule occur on a large scale.

Broadly speaking all rocks fall into two classes:

1. Those which represent a distinctly constructive phase of earth history.
2. Those which owe their origin to destructive agencies.

The first are the igneous rocks.

An igneous rock is one formed by the solidification of a molten elemental mass, either upon the surface of the earth or in its depths. The igneous rocks are characterized in general by their massive structure, that is, they do not show true bedding or stratification, though in volcanic flows the successive layers may closely resemble bedding. All except the very fine textured igneous rocks may be recognized by their crystalline composition; crystals show characteristic cleavages, and straightedged outlines. Or if the rock cooled very slowly, the crystals will not have developed straightedged outlines, but will have grown together along irregular boundaries. The rock mass, however, is evidently made up of different kinds of materials.

In taking up the study of the igneous rocks the first fact that impresses the student is that there are no definite lines of demarcation between the different types. One geologist may give a rock one name and another may place the same rock in a different group. This is because these rocks form a series in which one type merges gradually into the next, and the transition specimens may be put into either class. For instance, a rock containing orthoclase, and plagioclase feldspars, quartz, biotite, and hornblende, might be classed either as a granite or a quartz diorite. The distinction between the two being that in a granite orthoclase is the predominant feldspar, while in the quartz diorite there is more plagioclase. Thus it is clear that the classification in such a case might be made differently by different observers.

The reason why igneous rocks form a graded series is that they result from the cooling of molten masses which are really solutions of the rock forming elements. When such a solution, technically called a "magma," solidifies, the conditions of temperature and pressure determine the progress and nature of the crystallization of the mineral-forming elements; and since these conditions are subjected to variations the resulting rocks show corresponding differences. Again the chemical compositions of different magmas may show various gradations which determine the type of the resulting rocks.

Consequently the only absolute classification of igneous rocks is based upon the chemical composition, and the ratios of the various chemical constituents to each other. (Refer.: Cross, Iddings, Pirsson, and Washington, "Quantitative Classification of Igneous Rocks.")

But in the field the classification must be made according to rock texture and mineralogical composition.

Rock Textures.—It is evident that if a molten mass is chilled very quickly the processes of crystallization will be entirely arrested or confined to merely the initial stages. At one end of the scheme of classification based on texture are all those types of varying chemical and mineralogical composition which cooled very rapidly giving glasses. These may have been poured out upon the surface, or may have been brought suddenly into contact with cold rocks underground.

If crystallization had just started developing a few crystals in a non-crystalline, or very finely crystalline matrix, the texture of the rhyolites, dacites, basalts, etc., results. The texture is said to be "felsitic" when the rock is made up of crystals too small to be identified.

If the groundmass, or matrix, forms a greater part of the rock than the phenocrysts (crystals with complete crystal outlines), the texture is porphyritic and the rocks are called rhyolite (or andesite, or basalt, etc.), porphyries.

With the phenocrysts forming a greater proportion of the rock than the ground mass, the texture is also porphyritic, but the name of the next succeeding group is prefixed, giving the granite porphyries, gabbro porphyries, etc.

The granitic or granitoid texture results when the rock mass has cooled very slowly, so that all the constituents crystallize before any particular ones have finished their growth. In this division belong the granites, diorites, gabbros, etc.

The division into vertical columns Table II, is based upon mineralogical composition, and to place a specimen according to this classification, it is necessary to be familiar with the principal rock forming minerals which are:

Quartz
Orthoclase feldspar
Plagioclase feldspar
Biotite
Hornblende
Pyroxene
Olivene

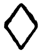
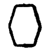
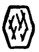
Nephelite and leucite belong to a series of rare rocks not easily differentiated from the related types in the field.

Quartz cannot be scratched with a knife, and has a glassy appearance on fresh surfaces. It occurs in rocks (1) in crystalline form showing a hexagonal cross-section. The corners may be so rounded as to make the crystal resemble a rounded grain. (2) Quartz also occurs as cementing material or ground mass between other crystals. It is usually colorless or "smoky."

Orthoclase feldspar may be scratched by quartz. When fresh it is scratched only with difficulty by a knife blade; as it alters or weathers it becomes clayey and is readily scratched. It is distinguished by its cleavage; it breaks in a blocky manner with the shining cleavage faces at right angles and showing no grooves (striæ). The color is white, pale yellow, or pink in mass.

Plagioclase feldspar is scratched by quartz, but only with difficulty by a knife blade when fresh. Upon weathering it becomes cloudy or clayey and soft. The cleavage is in two directions, nearly at right angles. The plagioclases are distinguished from orthoclase by flashing the shining cleavage faces so that they reflect the light, when they will show grooving or striations, which look like fine parallel scratches. The surface may also show a play of iridescent colors. The color is usually gray in mass.

Biotite is readily scratched by a knife blade. It characteristically occurs in flakes or scales which may show a six-sided outline. The crystals can often be separated into thin leaves. These plates are elastic. The color is black or brown in mass.

Hornblende is scratched with difficulty by a knife blade. The crystals are characteristically long and narrow (prismatic), the cross-section is rhombic  or six-sided  with cleavage angle of about 120 degrees between the adjacent faces. The section, especially if polished, will show these cleavages making a diamond-shaped network,  . The color is dull dark green to black in mass.

Pyroxene scratches with a knife blade. The crystals are usually short. The cleavage angle is nearly 90 degrees between alternate faces of the eight-side cross-section, as indicated in the sketch . The distinction from hornblende lies in this cleavage and the shorter crystal form. The color is pale green to nearly black.

Olivine scarcely scratches with a knife. It usually occurs in translucent grains; it is insoluble. The color is characteristically green, also yellow. The grains often resemble fragments of broken bottle glass.

In naming rocks, it is desirable to keep as closely to general practical usage as may be consistent with scientific requirements;

it is always well to remember that an unusual or unfamiliar name applied to a familiar rock creates more or less suspicion in the mind of the practical miner. If you wish to meet him on his own ground it is just as well to fall into the local usage which may be more or less inaccurate from a strictly technical standpoint.

In the field it will often prove impossible to distinguish with certainty the minerals necessary to put a rock in its proper place in the table. Or it may be that rocks will be encountered which apparently have no place. When this is the case the specimen should be put with the group it most closely resembles, with a qualifying description.

The following list of the commoner rock names, not included in the table, may be of assistance:

Anorthosite, a rock composed mainly of labradorite.

Aplite, a rock of finely crystalline granitoid texture, occurring in dikes.

Grano-diorite, a rock intermediate between granite and quartz diorite.

Monzonite, a rock in which orthoclase and plagioclase feldspars are about equal.

Latite, a type between trachyte and andesite.

Metadiabase, an abbreviated form for metamorphic diabase, refers to a metamorphic rock resembling a diabase, but of a sedimentary origin.

Metadiorite, a rock of sedimentary origin metamorphosed and resembling a diorite.

Pegmatite, a coarse granite, occurring in dikes which may merge into quartz veins.

The following names are recommended for field classification when the rock is of such character that it cannot be identified with certainty:

Felsite, a fine-grained rock of light color.

Trap, a fine-grained rock of dark color.

Dolerite, a rock containing any ferro-magnesian mineral (hornblende or pyroxene) with subordinate feldspar of any kind.

Clastic Rocks.—A clastic rock is one composed of fragments of some earlier formation.

The clastic rocks may be separated into four classes:

1. Material laid down from mechanical suspension in water.
2. Material ejected by volcanoes, possibly deposited with a good deal of water.
3. Material transported by the wind.
4. Material deposited from solution.

The rocks of the first class are commonly called "sedimentary rocks," since they are laid down as sediments from water, in river beds, lake and sea bottoms. The distinguishing feature of sedimentary rocks is bedding, or stratification; this results from the laying down of successive layers of material of different character, which may be seen on any beach at the present time. Close to the shore are larger stones and pebbles, further out sand is deposited; a slight subsidence of the shore line would result in sand being laid over the pebbles; if the sinking continued, mud would cover the sand, and the next stage, if it were an ocean bottom, would be the deposition of shells and skeletons of marine animals. Due to the pressure of overlying beds, such a series would finally appear as conglomerate, sandstone, shale, and limestone.

In general, rounded polished surfaces are typical of the sedimentary fragments; the material is usually sorted or classified, since coarse material is not transported so readily as fine sand or silt. Other traces of water action, such as ripple marks, may also be seen.

Glacial material is usually unsorted (but may show water polishing) and the different fragments may be quite different in origin.

Volcanic material may consist of coarse and fine fragments together, or may be classified to some extent as a result of heavy rains accompanying the eruption. The resulting tuffs and breccias are sometimes very hard to identify, especially when they have been subjected to alteration or metamorphism.

Exact classification of the sedimentary rocks may be made on the basis of the size and shape of the component fragments, but for field work it will be sufficient to place the rock in the following tabulation:

A. Breccia—angular fragments cemented.
  1. Fault breccia, formed of the fragments crushed in fault movement.
  2. Talus breccia, resulting from the accumulation of broken fragments upon a slope.
  3. Volcanic breccia, fragments ejected by a volcano or caught up in an igneous mass.

B. Mechanical sediments.
  1. Conglomerate, a rock consisting of cemented fragments of varying sizes, showing water action, or wind polishing.
  2. Arkose, a sedimentary rock consisting of feldspar, quartz, and possibly mica.
  3. Graywacke, a rock containing other silicates than quartz.
  4. Sandstone, composed of quartz chiefly, rounded grains, relatively small and water sorted to finer sizes.
  5. Shale, composed of the finer material, usually clayey, deposited after the fine sandstones.
  6. Clay and marl, the last products of the sorting and water deposition processes.

C. Organic sediments.
  1. Limestones, made up of calcareous shells, and skeletons of marine animals.
  2. Infusorial earth, composed of the minute siliceous shells or skeletons of microscopic marine animals.
  3. Siliceous sinters, or hot spring deposits.

D. Other organic remains, and chemical precipitates.

In this group come the iron ores, coal, gypsum, salt, etc.

The Metamorphic Rocks.—This group perhaps forms a larger part of the earth's "crust" than the other two combined, since it is comparatively rare for a rock formation not to be changed to some extent. But since the metamorphic rocks are other types altered, it is hardly necessary to attempt a complete separate classification.

The agents of metamorphism are: (1) dynamic action—folding and shearing of the rock formations, and (2) chemical action.

When a coarse textured rock has been compressed, folded, and sheared, the crystals or fragments are elongated and the rock has a striped or banded appearance, which may in some cases resemble bedding. Such a rock is called a "gneiss," and may result from metamorphism of some coarser igneous type; thus, there are granite, gabbro, or diorite gneisses. A conglomerate gneiss results from the shearing of a coarser sedimentary rock.

If the leaves or laminæ are thinner, so that the rock splits readily along more or less parallel planes, it is called a "schist." The rhyolite and andesite schists are derived from the corresponding igneous types. The schists are often classified according to the chief ferro-magnesian mineral present—so that there are mica schists, hornblende schists, etc. Their origin is often obscure, usually a problem for microscopic determination at the hands of a trained petrographer.

Quartzites are formed by the metamorphism of sandstones; sometimes no trace of the original grains and bedding planes can be found in the field, in which case the rock may be confused with quartz of igneous origin.

Slates result from the metamorphism of the finer sediments under dynamic action. They are distinguished by blocky fracture or sheeted structure, due to the development of a cleavage at an angle with the bedding planes.

Limestones when closely folded show varying degrees of crystallization, ranging from large rhombic calcite crystals to fine sparkling "frosty" surfaces. The traces of fossils become very obscure, and even bedding planes may be obliterated. Impure limestones when metamorphosed form "ophicalcites," in which masses of serpentine are surrounded by calcite and dolomite.

Talcs and serpentines may result from the metamorphism of impure limestones, but are chiefly due to the alteration of basic igneous rocks.

Under the influence of chemical action various changes take place in the original rock types. The igneous rocks may be largely silicified and their original character lost. Limestones develop aggregates of garnet and other metamorphic minerals (see page 147). Replacement of limestone by silica gives a rock which may be taken for a quartzite; the texture is usually fine and traces of the original bedding may be found. Such silicified limestones are frequently called "quartzite," "flint," or "hornstone."

It is evident that the observer in the field has a variety of problems to confront him, some of which will defy solution by the examination of hand specimens. And this leads to the microscopic study of thin sections. The use of the microscope extends our powers of observation, first by magnifying the object which we are studying, and second through the distinctions which may be made by means of the optical properties of the minerals. There is an old saying to the effect that nobody can see any further into the ground than any one else, which is not entirely true when one considers the subject of optical mineralogy. If a section of a rock is cut and polished, mounted on glass, and then ground thin and polished, so that it transmits light, much more can be told about the relation of the various minerals than can be gathered from the hand specimens. In addition, when it is possible to make even the colorless minerals show different colors or marks by which they can be recognized, the problem of identification is much simplified. This is precisely what is done in optical mineralogy and petrography. But at the same time, the things that are to be looked for do not differ so much from those of the hand specimen or even of the rock masses considered as a whole, and the following tabulation may be used in the examination of these as well as the thin sections to which it particularly applies.

Table for the Examination of Rocks

A. Igneous Rocks
  1. Texture, historical deductions (*Cf.* page 147).
  2. Mineralogical composition.
    a. Essential minerals.
    b. Accessory minerals.
  3. Relative age of the minerals.
    a. Minerals formed with crystal boundaries are older than the surrounding ones, without crystal boundaries.
    b. Included minerals are older than those which include them.
    c. Minerals abutting without crystal boundaries are of the same age, approximately.
    d. Intergrown minerals are of the same age.
    e. Minerals cutting others are younger than those they cut.
  4. Alteration and Metamorphism.
    a. Degree of change, extent to which original minerals are changed.
    b. Character of the change, secondary minerals due to alteration, metamorphic minerals.

B. Sedimentary Rocks.
  1. Relative sizes and shapes of the component particles.
    a. Unsorted material, large and small fragments together, imply that the source of the material is near at hand or that the transporting agent is very powerful.
    b. Angular grains, fresh in appearance, indicate disintegration without decomposition, and little movement from source.
    c. Rounded grains, fresh, imply disintegration and transportation of the material.
    d. Sorted material, where the grains are similar in mineralogical character, indicates that the deposits

were made some distance from the source, or the original rock disintegrated and weathered also, differentiating the more resisting materials.

2. Look for fragments which give some clue as to the source from which the sedimentary material is derived.
3. Determine the character and probable origin of secondary or cementing material.

C. With metamorphic rock try to determine:

1. The nature of the original constituents and the original rock. Look for traces of original minerals in form or cleavage.
2. The nature of the alteration.
    a. Dynamic—folding, shearing, etc., distortion of crystals or fragments.
    b. Chemical change, older minerals partially dissolved by later ones.
3. The history or sequence of the changes.

A discussion of the methods of microscopic petrology is not within the scope of this book; the more especially so since it is intended primarily for use in the field where a microscope is not usually available. There are several good texts on the subject which may be kept for reference in the office, and referred to as occasion demands.

In addition to the examination of specimens with hand lense and microscope, any simple chemical test for composition should always be made. The limestones effervesce with dilute hydro-chloric acid, but when testing this way for a carbonate, care should be taken that some secondary form, such as a calcite film, does not lead to wrong conclusion. Blow pipe tests may sometimes be made with advantage to distinguish obscure minerals. In this connection it may be well to refer to the chapters on recognition of minerals.

Instead of giving detailed descriptions of the various rock types, Tables I and II have been prepared with the idea of condensing and putting into practical form much of the material

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		s Indistinctly bedded	Sedimentary rocks Structure distinctly bedded
Rock is composed of materials differing in shape, size, or color.	**Compon *crystals,* ing clea other charact**		
		Arkoses—crystals slightly rounded, not closely intergrown.	
	Compone clearly varied *mented* t		
			Conglomerate.
			Breccia. (Often shows no bedding.)
	Rock is shells o marine s		Limestone.
Rock is composed of materials similar in color; size and shape of component particles often indistinguishable in hand specimen.	**Material i dividual distingui specimen *Exception* crystalli shows r cite.**	Quartzite, chert, silicified limestone; silicified shale.	
		Finely crystalline limestone, color white, pink, bluish-gray.	
		Slates. Bedding obscured by slaty cleavage.	Shale, characteristically thin bedded; colors, gray, black, or red.
	Individua small sca		
	***Rounded* ous, are ed by kni pick.**		Sandstone.
		Quartzite.	

Note.—Table does not inclu

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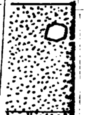
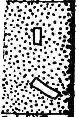
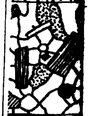
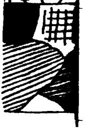
		gray, dark green, to black		
Occurrence				
Volcanic flows, surface, margins of dikes, and sheets.		Basic glasses Basalt obsidian, scorias, tachylyte		
Surface flows, marginal to dikes.		Trap		
		ll letters, any or all of these may occur		
			Without Feldspar	
		ENES	AUGITE, Hornblende, Biotite	
	Text	OLIVINE		OLIVINE
Surface flows, dikes, and sheets.		Basalt.	Augitite.	Limburgite.
Dikes and other intrusive bodies of moderate size and depth.		Basalt Porphyry.	Augitite Porphyry.	Limburgite Porphyry.
		Olivine Gabbro Porphyry.	Pyroxenite Porphyry.	Peridotite Porphyry.
Masses of great size, and depth.		Olivine Gabbro.	Pyroxenite.	Peridotite.
Surface deposits, more or less bedded or stratified.				

***Note.*—This table is ad**

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usually given in descriptive texts. As a reference book, or a text-book, Prof. Kemp's "Hand-book of Rocks" will be found to be a concise, and yet fairly comprehensive treatise, taking up at length a subject which is only outlined here as an aid to geological field work.

CHAPTER XIII

GEOLOGICAL PROSPECTING

Outfit.—Lists of the different outfits will be found in the appendix. It is my intention here rather to state general requirements and give some ideas which may serve as a guide in getting together an outfit. The supplies carried in any given case will, of course, depend upon the nature of the country to be prospected, distance from base of supplies, means of transportation, time that the expedition is to be in the field, number of the party, and the natural resources of the country. In general it may be said that everything should be as light and compact as possible. The cooking utensils should be of tin or aluminum and the pots, cups, and plates should fit one within the other so as to take up as little space as possible. Very complete outfits of this kind can be obtained from most dealers in sportsman's supplies.

Canned stuffs are too heavy and bulky for transportation on long trips. The staples—flour, cornmeal, beans, rice, bacon, tea, cocoa and coffee—should be relied upon as much as possible. The condensed and evaporated foods may also be taken. For a complete list refer to the tables mentioned above.

If the members of the party are to pack their own supplies, pack straps should be carefully gone over and adjusted, and an experienced man should be at hand to assist in making up the pack. It is a good plan for men out of training, or new to packing, to accustom themselves to it before actually going on trail, else the consequences may be painful and disastrous to the start, at least, of the expedition.

When pack animals are to be used, the saddles should be thoroughly overhauled; old straps, buckles and loose rivets should be attended to. Canvas bags are provided to hold the loose articles of the outfit and food should be packed in smaller canvas sacks. The outer bags and the canvas to cover the pack should be waterproof. Canteens and water bags must be taken in dry countries. It should be seen that the packers are provided with horse shoes and nails, extra rope, straps, and buckles, harness awl, and rivets. Nothing is so annoying as to have to stop on the trail to make repairs when there is nothing on hand to repair with. The Mexican freighters especially are likely to go into the field poorly equipped and trust to ingenuity, luck, baling wire and string, to come out all right. They are also likely to appropriate any extra supplies furnished them. It is important that the animals should be kept in good condition, free from saddle galls, and sound at the feet.

It is equally necessary that the members of the party keep their feet in good condition. They should be well provided with foot gear and on a long trip a man who knows something about shoe repairing should be attached to the party. At any rate, a shoemaker's iron last should be carried for the discouragement of nails in the wrong places; awl, heavy needles, and waxed thread will pay many times for the trouble of carrying them. Hob nails, or wood screws used as such, should be replaced as soon as they are lost.

As to clothes, it is not possible to lay down strict requirements; they should be suited to the climate, heavy kahki and corduroy are most serviceable, but the latter is not adapted to use in warm countries. At least one change of shirts and under clothing should be carried when circumstances permit; several pairs of heavy socks should be taken and woolen socks may be worn even in the warmer countries. In the mountains it is well to wear heavier under clothing, preferably woolen, even in the warmer weather, especially when it is cold in the shade or after sun down.

Sleeping bags are convenient in cold weather but are bulky. It is better to carry several light blankets than a single heavy one, and the rubber blanket or poncho is a very good thing to have. With people who are unaccustomed to sleeping in the open, the tendency is usually to carry too much bedding.

In one's personal kit should be included the necessary toilet articles in such shape as to take up as little room as possible, also needles, thread, and cloth for patching. There should be at least one medicine case in the party, including the simpler remedies, adhesive plaster and tape, absorbent cotton, and a roll or two of bandages.

Unless an expedition is organized on a large scale, every man must be his own doctor and should go into the field in good shape physically. The chances are that as long as he takes proper care of himself he will stay in good shape, barring accidents, such as broken bones. In such work it is necessary that a man should take all proper precautions to stay fit or he will impair his own efficiency and put an added burden upon the other members of the party. It is, of course, desirable that in such a party one man should have a knowledge of medicine and surgery, or at least be familiar with "first aid" methods.

Maps, Instruments and Methods.—In starting into a new country it is always desirable to have the best maps obtainable of the district to be covered. The government land surveys or geological surveys publish maps in the United States and Canada; and in many of the Mexican mining districts maps of more or less accuracy may be obtainable. Where no maps are available it becomes necessary to work them up by reconnoissance methods as the work progresses. Map making is out of the field of ordinary geological work, but the geologist should familiarize himself with the methods employed.

If a large area is to be covered, it may be necessary to determine latitude and longitude, so that a chronometer will be carried for accurate time, and a small transit will be used for solar or stellar observations. The sextant is more convenient to carry, but is not so accurate, while the transit has the additional advantage of use in ordinary surveying. An aneroid barometer is useful in determining approximate elevations as the march progresses and in finding local differences of elevation with considerable accuracy. Field glasses, range finders, and a pedometer or passometer, are valuable adjuncts in sketch mapping.

The large plane table is useful in mapping in open country, and triangulation may be carried out extensively by means of it. A convenient form of alidade is illustrated in Fig. 3. The small plane table may be used for less accurate work and local sketch mapping.

The army sketching case is a drawing board of small size, provided with rollers for carrying a long strip of paper. Upon the board are a compass and sighting device, also a movable protractor for plotting sight lines and distances. This makes a most convenient board for sketch work when traveling upon roads or trail or simply running a traverse line. Distances may be estimated or measured with the pedometer or passometer, or some range finding device, while elevations may be taken by barometer or measurements of slope angles in connection with distances estimated or measured.

Triangulation from a base of known length is a quick and accurate means of measuring distances and locating new points. If the locations of several prominent points of an area have been determined, the re-section method of plane table location (see page 4) is very convenient for locating new points. For rougher sketch mapping in open country, the following method may be used.

A base line is measured roughly by stadia, tape, or pacing, and is laid out upon the plane table sheet. From both ends of this line prominent points are sighted and located by intersections upon the map. Such points may then be occupied and new locations made, gradually extending the field of the map as longer bases or triangle sides are available. In the arid country of the Southwest, which is characterized by ranges separated by wide stretches of plains, where the observer can see for long distances, such triangulation may be carried out easily and quickly and will give fairly satisfactory results. Locations made by sighting the peaks of the opposite range will be much more accurate than those made from estimated distances over rough country.

Sampling and Assaying.—When prospecting far away from centers of civilization, it is very desirable to sample and assay ores in the field, since samples quickly increase the weight of the pack and only a limited number may be carried. For this reason it is well to establish a base from which to work where an assay outfit and forge may be set up. This is particularly necessary if any development work is to be done. In this case a complete sampling and assaying outfit may be installed and the powder and steel for mining operations are stored at field headquarters. Even when such a plan is adopted wherever supplies and equipment have to be transported over bad roads or by means of pack animals, care must be taken to assemble as light and compact an outfit as possible.

When the field party is small and is moving about a great deal, much of the more elaborate outfit must be discarded. For sampling hard siliceous outcrops, a few gads and a "single jack" hammer may be carried. The gads must be sharpened by makeshift methods since a forge and blacksmith coal cannot be carried. Charcoal may be burned after a fashion in the field and a rough forge constructed on the ground if a small bellows is carried to furnish the blast, with a piece of iron pipe for a tuyere. Samples from less resistent outcrop may be taken with prospecting picks. Canvas sample sacks and a sheet of canvas for rough quartering, and oil cloth or sheet rubber for quartering finer material, may conveniently be carried. Envelopes for pulverized samples should also be provided in case it is desirable to carry them any distance. For pulverizing, the bucking board and muller are discarded because of weight, so that a mortar and pestle must serve this purpose. The steel mortar need not be very large, because the first crushing may be done with the hammer on a flat stone.

For qualitative determination of the ore, no very elaborate outfit is required. The specimen may be roasted in a wood fire, or may be pulverized before roasting, and panned for gold, native silver and copper. The ordinary gold pan may be used; it will also serve as a bread pan for the cooking outfit. If water is scarce, the horn spoon is a better panning device than the pan.

The methods giving by Prof. Moses, in the chapter on "Recognition of Minerals" also include blow-pipe tests so that a small compact blow-pipe outfit should be carried. The candle flame is most available for use in the field.

The quantitative blow-pipe methods are not so satisfactory, and while they may be employed, it requires considerable skill to get good results. On the whole it seems better to carry a portable assay outfit as outlined by Mr. S. K. Bradford in the following paper:

A PORTABLE ASSAY OUTFIT FOR FIELD WORK[1]

By S. K. Bradford

For years past I have traveled in quest of promising mining properties, over almost impassable mountain trails to remote places in the mining regions, usually many miles from an assay office.

If, upon examination, the formation and the ore deposits appeared favorable, a quick determination of the value of my samples was necessary, in order that I might take intelligent action with reference to the acquisition of the property. A journey with my samples to civilized regions often meant weeks of delay, and perhaps loss of opportunity. How many, under similar circumstances, have returned with their assay results from such a journey, only to find that some audacious speculator had "optioned" the property! True, a first payment could have been made and the chances taken on the results; but experience has taught that rich looking ore is not of necessity valuable. Personally, I would not hazard a ten-dollar bill on any property without first determining by assay the value of the ore.

[1] Published in part in *Bulletin of American Institute of Mining Engineers*, January, 1911.

To carry the usual complete assay paraphernalia over such mountain trails was impracticable by reason of the loss of time involved, the great expense of transportation (charged according to weight), and the fact that a few such trips would almost certainly wreck the outfit.

For these reasons I began a process of elimination and substitution which finally enabled me to carry, in an ordinary 26-in. valise, sufficient apparatus and supplies for, say, 100 assays of adequate commercial accuracy. My final outfit was as follows:

Apparatus.—Small hammer; steel motar (2.5 in. wide, 3 in. high, with stand sawed off flat, so that it can be used as an anvil and for slag molds); small steel pestle; blow-pipe and blow-pipe cupel holder; small spatula; large spatula; button pliers; light 1-in. cupel mold; two 3.5 by 8-in. muffles; 18 "F" crucibles and 6 crucible covers; short crucible tongs; 25-c.c. burette; six 0.5-oz. Denver parting bottles; six 0.5-oz. Berlin annealing cups; two or three beakers; hand balance, such as used for weighing gold dust (folding in tin box), and set of gram weights; a 6-in., 60 mesh screen; 6 small glass stirring rods; teaspoon and tablespoon of usual camp style; and a micrometer for measuring the diameters of buttons. (This may be a short, fixed microscope stand, in which has been placed a scale of 0.1 millimeters—two or three extra object glasses being carried for safety. If one is willing to be burdened with the extra weight and bulk, a small portable button scale and weights may be substituted. The micrometer, however, is sufficiently accurate, and possesses the advantage that if one's mule should roll down the mountain it will be uninjured, whereas a scale may be hopelessly ruined for further immediate field use.)

Chemical Reagents.—(To be carried in bottles inclosed in metal cases): 0.5 lb. of potassium cyanide; 1 lb. of C. P. nitric acid; 1 lb. of C. P. hydrochloric acid, and 2 lb. of aqua ammonia.

Other Regeants and Supplies.—A few ounces of sheet copper; 1 oz. of C. P. sheet silver; 0.5 lb. of sheet lead; 2 lb. of 10-penny wire nails; 5 lb. of bone-ash; 5 lb. of sodium bicarbonate; 5 lb.

of litharge; 3 lb. of red lead; a few pieces of prepared charcoal for blow-pipe use; half a dozen miners' candles and a half a dozen old newspapers.

Practicable Substitutes in the Field.—Sodium bicarbonate can be obtained at most country stores. If the supply of litharge be exhausted, red lead (used in the proportion of about 3 assay tons) makes a fair substitute. For a long trip I increase my supply of bone-ash and litharge. Under extreme conditions I have been compelled to get bone-ash by calcining and pulverizing old bones, and to substitute powdered beer bottles for borax, filings from coins (of known fineness) for silver, and flattened bullets for sheet lead. If, as is not unlikely, the supply of beakers should have been destroyed en route, beer bottles with the tops broken off constitute a tolerable substitute—and, I need hardly say, can be obtained in abundance at all mining camps!

The outfit above described can be packed in an ordinary valise, say 26 in. long. To illustrate its use in the field, I present the statement which follows:

Gold and Silver Assay.—The ore sample is broken to very small size, quartered, and passed through the screen. The final assay sample 0.5 A-T. (unless the ore be very poor, but up to 2 A-T., if necessary) is weighed in the gold hand-balance. To a sample of 0.5 A-T., add one even teaspoonful of litharge. If the ore is very heavy with sulphides, 5 even teaspoonfuls of red lead and 10 nails may be substituted. To this should be further added a "heaping" tablespoonful of sodium bicarbonate, and another of borax, for which, if the ore is very basic, ordinary powdered glass may be substituted, or also added. The final addition of 0.5 grm. of wheat flour or powdered charcoal will give, after melting, a lead bottom of from 7 to 8 grm. weight, unless the ore contains a large proportion of heavy sulphides. The sample should be thoroughly mixed, wrapped in newspaper, and properly numbered for future identification. If the ore be believed not to carry sufficient silver for successful subsequent parting, a small measured portion of C. P. silver may be added.

For crucible melting, a blacksmith's forge is available in every mining camp. In using such an apparatus for this purpose, a small inclosure of brick or loose stone should be placed around the tuyere of the forge, built up nearly even with the tops of the crucibles, and a layer of coal or coke should be put directly over the tuyere on which the crucibles stand. The spaces between the crucibles and the walls should be filled with fuel. The crucible and covers (or, in case of muffle roasting, the muffle) should be thoroughly dried and warmed beforehand, to prevent cracking. The charge having been put into the crucible, with a layer of borax on top, the crucible cover put on, and the whole covered with charcoal, it is only necessary to take care not to make too hot a fire (thereby melting off the bottom of the crucible) and to turn the crucible from time to time, in order to secure an evenly distributed heating. During the roasting process the crucible cover should be removed.

If the fluxing was correct, the melt will pour well, and the crucible can be returned to its place in the fire, and the next charge, paper and all, put into the hot crucible. There need be no fear that the crucible will "salt" the subsequent assays.

With care one can make from 6 to 18 assays in each crucible. Fuel must always be kept between the bottom of the crucible and the tuyere iron. Unless the samples are very base, from 15 to 30 minutes will be sufficient, after the first melting, to melt each lot of four.

When all the samples are melted and ready for cupellation, remove the stone or brick around the tuyere, and place on each side of it a brick (or a flat stone of about the size), the two being about 6 in. apart. On these place the muffle, forming a bridge over the tuyere, with the mouth of the muffle facing the front of the forge. In using stones for this purpose care must be taken to select those that will not spall under the heat and break the muffle. Set the muffle level and build a wall around it, excepting a front space, about 3 in. away from the muffle, and to about the height of its top. Cover with charcoal, and keep plenty of fuel always under the muffle on the tuyere. Put in the empty cupels and close the mouth of the muffle with a piece of charcoal or coke whittled to fit it. After the muffle has become hot put in the buttons.

In the absence of charcoal or other suitable fuel, I have made charcoal in an open fire or fireplace by a liberal use of water to cool it or by covering the charred fuel with dry dirt.

The above method of fire assay requires less fuel than any charcoal furnace I have ever used; and I have often made, in this crude way, 40 assays in a day. The buttons come out clean and bright; and the cupellation requires but a few moments longer than in a regular cupelling furnace.

Sometimes the muffle breaks, and must be set up on pieces or iron running lengthwise, and plastered with clay to hold it together. When a muffle is entirely gone beyond such patching and no other is to be had, a new one may be drilled out of a brick. But I have often made 20 runs with one muffle.

Having cupelled all the buttons, one should find some place out of the wind and, if one has the scale, part and weigh the gold in the usual manner. If using the micrometer, measure the diameter of the button and determine its weight by a previously prepared scale based on specific gravities, multiplied by solid contents. This method of determining weights was published (Trans., XXXI, 800; 1901) by Luther Wagoner of San Francisco some 10 years ago (see p. 204). After parting, the gold is dried, wrapped in a small piece of sheet lead and cupelled with blow-pipe and miners candle on a little bone-ash pressed into a cupel holder. The button being perfectly round, the weight is determined by measuring the diameter, as described. The cupel holder is made from a piece of volcanic tufa cut down to a cylinder in form, about 1.5 in. in diameter, and 2 in. long. The top is hollowed out like a bowl about 0.5 in. deep; and a small hole, 0.5 in. long and about 0.25 in. in diameter, is cut in the bottom. Into this hole fits a piece of wood, which the assayer can hold in his left hand, so as to turn the cupel holder with his thumb and forefinger, and make a perfect button. The tufa having been heated in a fire to a red, nearly white heat, and then dropped into water, comes out as hard as a rock.

A few years ago, I forgot, on one trip, to take with me the pulp scale and weights; nor did I discover the omission till I was ready to weigh the pulp, in a locality more than 100 miles away from the nearest town. I melted the tops from two Carnation cream cans, and punched three equidistant holes, thus making pans for a scale. Then I put a common dressing pin through the middle of a thin strip of pine, and another through each end, at equal distances from the first; balanced the stick; hung my pans to it; and having balanced these, was ready to weigh the pulp. I had a worn half-dollar silver piece, which, with a new 10-cent piece, would exactly balance a new half dollar, weighing 205 gr. Then, by adding a 5-cent silver coin, I had 230.625 gr., near enough for my purpose to one-half an assay ton.

If one doubts the existence of any commercial value in the ore, one may carefully weigh out 0.5 gr., run it down on a piece of charcoal, and measure the button with the micrometer, even though it be so small that the natural eye cannot see it. In this way, the trouble of making a regular assay may often be avoided.

Copper and Lead Assays.—For volumetric copper assays, it is necessary to standardize a solution at each camp; since it is impossible to transport the solution without standardizing it when next used. Therefore it is best to throw away the old solution when packing, and make a new one when required. Often I make rough fire assays of copper, to determine whether it is worth while to investigate the copper value thoroughly. This can be done in connection with the melts for gold and silver.

Lead can be determined in the same manner. An excess of carbon should always be used in the charge for lead. It is advisable to keep a duplicate sample of each assay, and have it checked on the return to civilized regions. After one has become familiar with the above plan of assaying, however, the testing by duplicate assays of such preliminary determinations of probable value will soon be discontinued.

For the Miner and Prospector.—The above article was written for the benefit of those engaged in the mining business presuming knowledge of assaying. I will now add a few suggestions, which, taken in connection with the foregoing notes, will permit prospectors and miners to determine the values of any ore they may find without the loss of time and the expense of a trip to civilization. The results will be sufficiehtly accurate for all practical purposes.

The ore is always rated in avoirdupois tons, while its contents are rated in troy ounces. There are 29,166.66 troy ounces in an advoirdupois ton. Therefore the standard assay ton consists of 29 1/6 grm. and each milligram of gold or silver obtained in the assay button being 1/29166.66 part of an assay ton equals 1 oz. of the same to a ton of ore. Usually the ore used is one-half of an assay ton and therefore a button of gold or silver weighing 1 milligram would carry a value of 2 oz. to the ton. The most common error indulged in by the prospector, is the selecting of specimens, assaying the same and then hypnotizing himself into the belief that he has taken an average of the vein.

Nearly all veins are in well-defined or separated streaks. Samples should be cut clear across each streak in a dozen places and the samples of each streak put on canvass and all pounded down by crushing on a rock or iron with a hammer to about the size of a small nut or less, and then the whole rolled and thoroughly mixed and quartered down, two quarters being rejected each time and the operation repeated until only a few ounces remain.

The beginner should provide himself with a 10-mesh wire screen and put the ore through it when the sample has been quartered to say 2 lb. The screen can be nailed to the bottom side of a cigar box, after removing the bottom, of course. The final two quarters should be put through the small 60-mesh screen. Then thoroughly mix on a small piece of paper or oilcloth, say, 12 or 14 in. square, by rolling from corner to corner, alternating with the diagonal corners. Then spread out the pulp with a caseknife in a thin layer, say one-quarter of an inch thick, on the sheet of paper or oilcloth.

With the pointed spatula or knife take out small quantities of pulp equally distributed over all parts of the sheet, being sure to take the pulp each time clear from the bottom. Place in a pan of the gold scales until it balances the one-half assay ton or 14.583 grm. Place this pulp in the small iron mortar, add a teaspoon even full (0.75 assay ton) litharge, 1/2 grm. wheat flour, 1 tablespoon heaping of bicarbonate of soda and 1 of powdered borax, if mostly lime and little quartz in sample. Add one tablespoon even full of powdered glass and for ore very heavy in sulphides from 1/2 to 5 grm. saltpetre (nitrate potash), mix thoroughly in mortar and put onto one-quarter of a common newspaper sheet and fold up same as a druggist would a powder of quinine, and neatly tuck the folded ends, one within the other, and put thereon the number of the assay.

If you suspect the presence of tellurium or any heavy volatilizing metal, substitute, say, four or five teaspoons even full of red lead. Warm the crucibles thoroughly and slowly, then put the charge therein, adding 10-penny nails from none up to ten, varying according to sulphides in the ore. Place the crucible in the fire beginning at the left back corner with one and put two in the rignt hand back corner, and carry your numbers always in this order from left to right. Also the same order is used in the muffle—in fact, keep this order in every process to the close of your assaying career and you won't mix your samples. Place on top of the assay charge in the crucible another tablespoon full of powdered borax as a cover. Many use salt as a cover, but in silver ore one is apt to form chloride of silver with loss in assay values. Put your crucible cover on and if using charcoal as fuel cover the crucible with it. Occasionally turn the crucible to prevent over-heating on any side. When the charge is nearly all melted remove covers to permit the free roasting of the sulphides. When the assays have settled and are at rest remove the nails, put on the covers and force the fire up. Then take out each crucible in its order, beginning with No. 1, and quickly pour the contents into the previously warmed moulds or mortar and set the crucible back into the fire, pick up the package containing No. 5 and drop it into the crucible with the crucible tongs, add nails and borax, cover, etc., as before. When your next set of assays are all in, cover and repeat operation as at first. Place the cooled No. 1 pour on an iron, say, bottom of mortar, or, if in use, the flat side of the axe, and carefully break up the slag and get out the button. If any detached pieces of bullion, put these onto the main button and pound with hammer till all are freed of slag and the button is in form of a square. This should weigh 7 or 8 grm. Scratch on this square the number of the assay. The pointed end of a three-cornered file is a good instrument with which to handle the lead buttons.

If the pour showed that the charge had been eating into the side of the crucible it is to be taken as a gentle hint that your assay charge was too basic and that it needs more pulverized beer bottle. If you do not heed the hint soon a hole will be made in the crucible, the charge will run out into the fire and the assay be ruined. If the pour is hot and yet thick and slow like molasses, the assay needs more soda bicarbonate, *i.e.*, too much quartz. Experience will soon teach you how to make a perfect fluxing if you pay attention to the signs.

As soon as your last melt is poured, rearrange your forge fire as per instructions in the first part of this article and put in your muffle and cupels, which have been previously made. In your fires for melting as well as cupelling you must pay strict attention to the foregoing instructions to obtain best results. As soon as the muffle is hot put in your lead buttons in the order above mentioned with the cupel tongs. Steady the tongs against the edge of muffle and carry the button directly over the top of cupel and drop gently into the cup, being careful not to crush the cup and not to drop the button over outside the cup and onto the bottom of the muffle.

It is well to keep a layer of one-quarter of an inch of dry bone-ash over the floor of the muffle so that in case of accident the ash will absorb the lead as otherwise the muffle may be destroyed. The button must not be held by the tongs too long in the muffle as it may melt before you can drop it into the cupel· As soon as buttons are in the muffle should be closed and the heat raised until the button clears and the lead vapor or fumes begin to rise. Then open muffle sufficient to allow free circulation of air and yet not enough to cool.

If vaporization is slow to begin, pieces of charcoal may be put in front or small bits of pitchy pine a little larger than a match. These will raise the heat enough to start operations. Great care must be used to prevent freezing, *i.e.*, the solidification of the button. If it does freeze raise the heat as just mentioned. You can also have the muffle too hot as well as too cold. A few trials afford the best instructions as to heat required. If after melting the button begins to shoot or splatter up little drops of lead to top of muffle, you will then know that the cupels were not hot enough. As soon as the buttons color, *i.e.*, as soon as the lead is expelled, the fumes will cease and the cooling of the buttons sends rainbow colors over them and the buttons assume a bright silver color. Remove cupels, mark on the proper number and put new cupels in muffle and repeat operations until assays are finished.

Now comes the final process, the weighing and parting of the buttons. I would recommend to the prospector the substitution of a small ivory scale for the micrometer or the button balance. This scale has holes in the top made to chamber the buttons. It costs $3 or less. Care must be used to see that the button fits the hole. The scale will indicate the value for silver and the value for gold for each sized button of either metal. Note the silver weight then place the button in the parting bottle and put in enough nitric acid to cover the button in bottom of bottle. The larger the button the more acid required.

Set the parting bottle on top of the muffle in a little bone-ash and allow the acid to boil. If enough silver was contained in the button the acid will give off nitrous fumes. Allow it to boil slowly until nitrous or yellow fumes have ceased and the acid is giving off white fumes. Remove bottle, dilute with soft hot water and allow gold to settle, then carefully pour off the liquid, allow the gold to remain in bottom of bottle, in a small compact black mass. Then put your Berlin annealing cup over top of bottle, hold tight and upset bottle and allow the gold to settle into the cup in a compact mass. Be sure to manipulate cup until black gold powder or sponge is in compact mass on one side of bottom of cup. Carefully drain off the water and set cup on muffle or other warm place to slowly dry. If dried or heated too suddenly there is danger of loss of all or a part of the gold. When heated put cup in muffle and heat gradually till cup is cherry red. Then remove and cool. If you have a button scale the gold being bright is now ready to weigh. If you have the ivory scale or the micrometer you must put the gold in a little cup-shaped piece of lead sheet, close up and run down into a gold button on bone-ash in the blow-pipe cupel holder. Manipulate till button is round, then measure and the assay is complete. In brief, if your ore contains little silver or no silver, you must add silver when you mix your crucible charge. If your button will not dissolve in the acid you can remove it and with the blowpipe add more silver and then part as above. You must have two and a half times as much silver as gold to part the same. The strength of your acid must depend on percentage of gold and silver in button. The more silver you have the weaker your acid should be, for the reason that weak acid leaves the gold in a mass and a strong acid scatters it in the bottle. I always dilute as I put acid in parting bottle, according to presumed need of each individual assay.

Your greatest trials will come in learning the use of the blowpipe. You must inhale breath through your nose and expel through the blowpipe, using mouth as a bellows. The flame must be steady and uninterrupted. You will soon learn how to manipulate the same and to distinguish the difference between the oxidizing and reducing flames and their uses. A common candle makes a fair heat. You must be certain that the lead is expelled from every button, otherwise you will have more silver in results than belongs there and your acid will not part the same. You must subtract the weight of the gold button from that of the button before parting, as otherwise results will show too much silver.

The Wet Copper Assay.—First weigh out 1 grm. of ore, add quantity of powdered charcoal, increasing to correspond to quantity sulphides in ore, and put in roasting dish if you have one, otherwise on sheet iron. Heat red hot and continuously stir until charcoal is consumed and sulphur all burned out of ore. Cool, repulverize, careful not to lose any of the pulp. Put in glass beaker, cover with nitric acid and heat on piece of wire screen or on sand heated in dish. Allow it to digest, then dilute, filling the beaker, say one-half full. Then filter and wash tails through filter a few times so that beaker will be three-fourths full. Then add aqua ammonia, stirring the same thoroughly until solution has a strong ammonia odor. If any copper is present the solution will turn blue. Set up your burette stand with burette filled with standardized cyanide solution. Drop into assay solution, thoroughly stirring same until solution turns clear, *i.e.*, loses its blue color. Note the cubic centimeters you have used and reduce by proportion to the copper as shown by the standardization of your cyanide solution.

To Standardize Cyanide Solution in the Field.—Weigh up 1 grm. of copper foil (you can use copper wire if you have no foil), dissolve in nitric acid as above. Dissolve cyanide of potassium in quantity[1] to make as much solution as you will need at that camp and keep solution in dark bottle in a dark place. Handle with care as this solution is deadly poison. Keep bottle well corked as solution open to air will lose its strength. Put in burette and drop slowly into copper-ammonia solution just prepared and note number of cubic centimeters used to destroy the blue of the solution. If it requires 50 c.c. cyanide solution you will have 50 c.c. solution = 100 per cent. copper—and therefore 1 c.c. solution equals 2 per cent. copper. If it required 10 c.c. cyanide solution to destroy the copper in your assay of the ore you will have as follows: 50 c.c. solution is to 100 per cent. copper as 10 per cent. is to the copper in your assay, which is 20 per cent. copper; or you can multiply your 10 c.c. solution cyanide used by standardized value, which 2 per cent. equals

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[1] In proportion of 20 grm. to 1 pint of water, for 1 c.c. = 1 per cent. copper approx.

20 per cent. copper. Thus your ore carries 20 per cent. of copper.

You can check your copper by fire assay, as outlined in the article above. In the wet assay of some ores, you will find elements that interfere with your assay, but by means of the fire check you can determine the copper contents accurately enough for all your purposes. In fire assays for either lead or copper your charge must, of course, not include litharge or red lead. It may be well for you to experiment on pulp, the contents of which are known until you become familiar with this method. If you wish to pursue assaying in a commercial way you can procure any one or all of a dozen text books which will treat of the things omitted by me. I am trying to help the man who finds a fortune but who may lose it because he may fail to have it assayed through negligence or financial stress.

CHAPTER XIV

GEOLOGICAL PROSPECTING (Continued)

"Well that's an awful lean and hungry lookin' country," said the Old Prospector.

"Why?"

"Can't tell exactly, but it is, does'nt look as if you would find much there, "shells (shales) an' quartz rock an' bull granite are no 'count anyhow."

In a general way the practical prospector recognizes differences in formations and by long experience comes to note unconsciously the signs which mean a good deal from the geologist's point of view.

Broadly it may be said that hilly or mountainous regions where the formations show folding and fracturing are the most likely places to look for ore deposits. This does not apply entirely to placers, nor to coal measures, and sedimentary deposits generally. The lead and zinc deposits of the Mississippi valley are also an apparent exception. But for the great majority of deposits the rule is good, because (1) there are usually intrusive igneous rocks which we believe to be the primary cause of the mineralization; (2) the intruded rocks have been shattered and fractures formed for the deposition of ores; (3) erosion has been more active and has exposed the outcrops.

Regions in which igneous rocks are in evidence are more favorable, because of the usual close association of ores with these rocks. The acidic, or lighter colored rocks are more often associated with ore bodies than the basic rocks.

The central portions of great intrusive masses are not usually productive and we must look to their margins and especially their contacts with sedimentary rocks as the most likely places for the formation of productive ore bodies.

Of the sedimentary rocks the quartzites and shales are commonly associated with coal, but do not as a rule form the wall rocks for the productive portions of ore bodies. There are exceptions to this rule of course, as in the case of the Coeur D'Alene lead silver deposits in quartzites and schists; and also the native copper occurring in sandstones.

Limestone seems to be the most favorable sedimentary rock for the deposition of ores, because of its solubility, and it should be noted in this connection that lead is very commonly found in limestone.

Since ore deposits are of relatively rare occurrence, we would naturally expect their croppings to be characterized by unusual features, and as a general rule this is the case. So that it is a good rule for the prospector to investigate unusual natural features. In bedded formations, for instance, terraces mean softer beds and if we have to do with coal or iron measures, these terraces may be valuable indications, as may springs confined to a certain horizon by impervious clay layers, bearing a fixed relation to the productive beds.

In the dry regions limestone usually resists erosion more than the intruding igneous rocks, so that the contacts are sometimes marked by steep scarps. Or the limestone may be silicified in part so that these areas crop as dark rough hills at once attracting attention. Such silicified areas may indicate productive contact zones and should be examined more closely.

Veins may form prominent ridges or depressions depending upon their resistant qualities, compared with those of the country rocks, or they may show as notches or saddles, where they cross the ridges. In the first case they are, of course, easy to pick out and follow; while otherwise they may best be found where erosion has stripped away the detrital material. When a portion of a covered outcrop has been found and a strike and dip taken the course of the vein may be determined by the method described on page 117. If a topographic map is not available the prospector may stand on the outcrop, hold his compass edge in the plane of the vein and sight along it in the direction of the strike, thus roughly determining the probable course of the hidden vein, or to be more accurate he may set up his plane table on the outcrop and place the alidade at right angles to the line of strike of the vein and incline one of the sight veins to coincide with the dip of the vein. Then by placing a light board or sheet of cardboard against the incline vane he actually constructs a portion of the plane of the vein upon his table, and by sighting along this plane he may stake out the probable line of the vein and locate the best places for trenching.

"Float" is a valuable indication for the prospector; the name is applied to fragments of vein material which have been carried away from the outcrop. These may be traced up stream beds or hill sides until their source is discovered. Panning stream gravel in likely looking places will give information as to possible placer ground and will also tell a great deal about the nature of the country rock along the stream, and may give evidence as to out crops not represented in the float of hand specimen size.

The color of the outcrops of ore bodies is perhaps one of the most important features; it is certainly the one which attracts the eye most readily and so leads to further investigation. When an outcrop has been subjected to erosion and oxidation, iron compounds, chiefly the sulphides, are changed to the oxides, limonite and hematite. Limonite is brown to nearly black, or yellow like iron rust; Hematite is usually blackish red or cherry red. These oxides may be present in considerable amounts, forming a capping (the "iron hat") or they may simply stain the rest of the vein material. Red, however, is the prevailing color and such outcrops may be recognized at great distances. Manganese compounds are also quite common in veins; the oxides usually encountered are braunite, pyrolusite, and psilomelane; they are brownish-black or gray in color. Croppings of veins rich in manganese are usually darker than those in which oxide of iron predominates. The importance of manganese lies in the fact that it effects the solution of gold to a notable extent. (Refer.: W. H. Emmons, "The Agency of Manganese in the Superficial Alteration and Secondary Enrichment of Gold Deposits in the United States"—Trans. A. I. M. E., 1910.) In his writing on this subject, Mr. Emmons has emphasized the fact that where manganese compounds occur in gold veins, the gold goes into solution and is carried downward producing enrichment; so that placers and outcrops showing free gold are not so likely to be found in connection with manganese bearing veins.

Blue and green stainings are usually characteristic of copper bearing veins, though the outcrops may be so leached that such traces are removed. Copper may also be indicated by red oxide stains. Bright red and yellow powdery material may indicate lead. Yellow is characteristic of sulphur and also of some of the rarer metallic oxides.

When examining an outcrop, it is often possible to gain some idea as to the changes which take place in depth, by following the vein to exposures in canyons and valleys; here erosion has taken place more rapidly than oxidation and the original vein material may often be seen. If a vein is found to vary considerably in width down the dip, certain inferences may be drawn as to the changes which may be expected with depth. (Refer.: W. H. Emmons, "Outcrops of Ore Bodies"—*Mining and Scientific Press*, Dec. 4 and 11, 1909.)

This may be illustrated by two cases. In Fig. 63 the vein shown in section, which varies markedly in width, is more resistant to erosion than the country rock and the vein outcrops as a ridge. When the surface is at the level indicated at "*a*" there is relatively little vein material exposed, and it is eroded more rapidly; but when the surface has been cut to the line "*b*" a much larger amount of resistant material is exposed, and it is not so readily carried away and blankets the uneroded part of the vein. The result would be that from "*c*" to "*d*", erosion would take place quickly as compared to the portion of the vein from "*d*" to "*e*"; similarly "*e*" to "*f*" would be cut away much more rapidly than a corresponding length of vein from “*f*” to “*g*”. The chances are, therefore, that any given vein of this type will be encountered when the wider portion is exposed at surface, since, when this is the case, the outcrop erodes comparatively slowly and so holds the surface longer, while shorter transition periods are taken for the erosion of the narrower zone. It would, therefore, be expected that under such outcrop, the vein would decrease in width and this would not of itself be a cause for discouragement to the prospector.

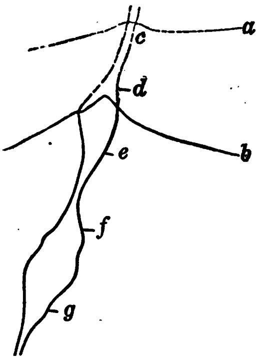

FIG. 63.

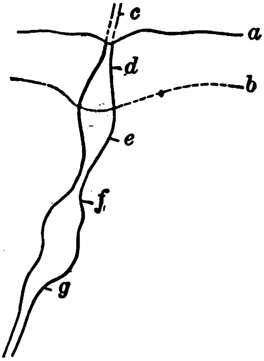

FIG. 64.

(*After W. H. Emmons.*)

On the other hand, if the vein be less resistant than the country rock and vary in width down the dip, there will be less chance for erosion when the narrower portion is exposed, as on the surface “*a*” of Fig. 64, and a maximum of erosion will take place when the greater width is exposed, as at “*b*”. The zones “*c*” to “*d*” and “*e*” to “*f*” will take longer to erode than “*d*” to “*e*” and “*f*” to “*g*”, with the result that we will find the former at the surface in the greater number of cases if we examine several veins of this type. So that when a deposit is recognized as belonging to this class it may be expected that it will increase in width below the outcrop.

TABLE III.—OUTCROP NOTES

General character of vein	Country rock	Appearance consequent upon erosion
1. Siliceous and resistant, poor in pyrite.	Limestone or some more easily eroded rock.	Vein outcrops as a conspicuous ridge, white, gray, to brownish in color.
2. Relatively rich in pyrite, less siliceous and more readily eroded.	As above.	Outcrop less likely to appear as a ridge, may occupy a depression, red color is distinguishing feature.
3. As in 1.	Igneous rock (granite or porphyry.)	Outcrop forms a ridge, unless much fractured, when it may weather out as a capping.
4. As in 2.	As above.	Vein may outcrop occasionally where quartz becomes predominant, but will form depressions where pyrite is strong. Best look for such veins where canyons or stream beds cut the formation.
5. As in 1.	Quartzite.	No marked topographic expression; must depend upon the character of the vein material for discovery.
6. As in 2.	As above.	Outcrop will probably be well obscured by quartzite débris, may be discovered in depressions.

In the Tables III and IV are given in condensed form various generalities and facts regarding outcrops which may be of value for reference. It should be remembered, however, that no hard and fast limits can be given in tables of this kind and that they are valuable chiefly as summaries. (Refer.: W. H. Emmons, as cited above. Also R. A. F. Penrose, Jr., "The Superficial Alteration of Ore Deposits"—*Journal of Geology*, Vol. II, page 288.)

TABLE IV.—OUTCROP NOTES

[*To face p.* 186.

Type of deposit	Chief ore minerals	Physical character	Other ore and gangue minerals	Oxidation and enrichment	Remarks
Vein or other concentrated type. Gold.	Free gold.	Finely divided.	Quartz most common.	Uncertain.	Gold may be carried away but is not likely to form a placer.
limestone.				be workable if enriched zone may be quite deep.	pect apparently barren limonite bodies if there are indications of copper bearing sulphides.
Contact zones.	Same as above. Sulphides may show an outcrop.	Same as above.	Same as above. Quartz. Iron minerals, including magnetite. Garnet and other contact minerals.	Leaching usually not deep.	Such croppings may have a dark silicified appearance and be called "blowouts" by practical prospectors.
Disseminated deposits.	Malachite Crysocolla. Chalcopyrite. Chalcocite. [Last two probably rare on outcrop.]	Staining. Fine specs and small stringers.	Pegmatitic quartz. Sericite.	50 ft. to 200 ft. of leached over burden common. Enrichment at depths less than 600 ft.	Country rock a porphyry or schist, shattered, and silicified on outcrop. Frequently impregnated with pegmatitic quartz. Slightly red or brown stained.

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CHAPTER XV

GEOLOGICAL PROSPECTING BY DRILLING

A field in which geological knowledge is of great importance is that of prospecting or exploring as it is often called, with drilling machines. The work of the geologists consists in the location of drill holes to the best advantage, the keeping of records of the drilling, and the interpretation of the data so obtained. Where the surface is not entirely covered by drift or vegetation, a geological map is the best basis upon which to plan drilling operations.

The drills used in mining exploration or development work are of two types. The core drills, of which the diamond drill is the commonest, use bits which are rotated by means of rods and the cutting is essentially an abrasive action. The bit is an annular ring upon which are mounted black diamonds or borts to make the cutting points, and the core passes back through the bit into the core barrel. One of the great advantages of the diamond drill is that it furnishes good specimens of the formation through which it passes. On the other hand, relatively little material is cut, so that samples for assaying are small, which is bad, unless the formation is extremely regular in its metallic content, as is the case with deposits of iron ore, for instance. Where the ground is much broken and fractured, diamond drill work is slow and also the hole is very apt to follow along some fracture plane.

The churn drill uses a heavy bit which is raised and lowered usually by means of a walking beam. The cutting is done by impact and crushing and it is unusual to obtain specimens suitable for ordinary rock determination. When specimens are found in the cuttings the chances are that they have been knocked from the upper portions of the hole in raising or lowering the tools. The ordinary churn drill hole, however, varies from 6 in. to a foot in diameter, depending upon the size of the bit and consequently gives a much larger sample than the diamond drill. In addition to assaying, much information as to the nature of the rock and ore may be obtained by panning the cuttings.

Drilling is a quick and relatively economical method of prospecting and is coming into very general use. Its chief application is to the exploration of bedded deposits, the large regular bodies of iron ore, and vein deposits where the vein material is uniform and the values are regularly distributed. It is not a good method to use with ore bodies that do not have a general tabular form, or those in which the values are "spotty" or scattered. The importance of keeping good records of drilling can hardly be exaggerated. The holes should be accurately located and careful records kept of the formations which are cut. In doing this, specimens must be saved and marked with the hole number and the depth or distance from the mouth of the hole. Daily reports are made by the drillers upon blanks provided for the purpose and samples are kept for assay and rock determinations. If a core drill is used, the specimens of the core are kept in proper order in core boxes or trays with grooves or compartments to keep the core from getting mixed. With a churn drill, before the sample is ground, representative material should be selected and put in a small envelope or bottle for record. The character of the country rock may be determined with more or less accuracy from the examination of this material with a hand lens or small microscope.

The geologist examines the core or cuttings, which may be panned at the drill or at the laboratory. He determines as completely as he can the nature of the country rock and the ore minerals. It is desirable to have a man especially trained in rock and mineral determination for this work, and if there are several drills on the job, it is better to have one man to examine the samples from all of them so that uniformity of results may be obtained. Any panning done by the drillers or samplers will serve as a check upon the further examination, but it is usually unwise to rely entirely upon this method for the records.

Blanks for daily reports of drilling should be of convenient size for filing. Cards are very satisfactory for this work and may be filed in a card index shape for easy reference.

Fig. 65 gives a form of daily report for diamond drilling which will practically explain itself.

For churn drilling a somewhat similar form, Fig. 66, may be used except that some additional data must be given. The following points should be covered by the daily reports in this work:

The number of the hole.

Location of the hole (by coördinates or otherwise).

Date.

Shift (day or night).

The number of the drill.

The size of the bit.

The depth of the hole, per last report.

The number of feet drilled.

The depth of hole at the end of the shift.

The size and number of feet of casing put in.

The total amount of casing in the hole.

Distance of water from surface when the first bailer of the last sample of shift was hoisted.

Time spent in (1) actually drilling, (2) repairing, (3) moving and setting up, (4) casing or pulling casing, (5) other delays.

The time report of the drill crew including names of the runner, helper, sampler, and hours employed.

Information regarding samples: The depth number of the sample (*e.g.*, 350 ft.–355 ft.); the number of bailings for the sample: the size of the sample taken (1/8 or 1/16, for instance, of the total material bailed); the length of sample; the amount of concentrates, the color of the sludge; the true depth; is the hole caving? (answer: No, or Yes, slightly, or considerably). Is the

RECORD OF DIAMOND DRILLING

______________Shift. ______________________191___

Where Working:______________________________

Section:______________________ Hole No.__________

	Feet	Core saved	Hours
Total depth of hole per last report....			
Moving and setting up..............			
Drove......in. stand pipe..........			
Drilled with chopping bit...........			
Drilled with diamonds..............			
Reamed from.........to........ft..			
Lowered.....in. casing to........ft..			
TOTAL DEPTH OF HOLE.........			

Kind of Material:______________________

	Feet	Size	Hours
Bit No............................			
Bit No............................			
Bit No............................			
Number of Men:....................			

REMARKS: ______________________________

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______________________Runner.
______________________Helper.
______________________Setter.
Report delays, accidents, etc. ______________________Foreman.

FIG. 65.

CHURN DRILL REPORT

Drill No.________ Hole No.________ Coördinates { ________ ________

________Shift Date________

Initial Depth ________

Drilled ________

Final Depth________

Depth to Water________

Drilling hours ________

Casing " ________

Fishing " ________

Delayed " ________

Cause of delay;________

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Sample No.	Color of sludge	Is sample reliable?	Caving	True depth	Length sample

CASING

Size	8½	6½	4½
Amount			

Drillers ________

Samplers ________

Helpers ________

Color of Sludge

1. Red or Dark Brown.
2. Light Yellow.
3. Pink or Purple.
4. Light Brown.
5. Gray or White.
6. Green or Blue.

Under "Caving" Record

No
Yes (if slight)
Yes X (if considerable)

If sample is not considered reliable, state reasons under Remarks below.

General Remarks

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FIG. 66.

sample reliable? The unsealed samples at the beginning of the shift with their numbers and the unsealed samples at the end of the shift, with their numbers.

The length of sample sometimes varies slightly from the stated distance for the cut, which may be 5 ft., or 10 ft., more or less, depending upon the requirements of the case. When the exact sample length has not been taken, the true depth of the sample will be slightly different from the depth given as the sample number; for instance, in the 350 ft. to 355 ft. sample, the sample length may be 4 ft. 6 in., and the true depth will be 354 ft. 6 in., instead of the exact 355 ft. In sampling it is usually desirable to use some mechanical sampling device such as a split divider.

In addition to the points covered above, which are the essential ones, it may be well to add upon the report blank, lists of the rock minerals, the ore minerals, and colors of sludge which may be checked off for each sample. The color of the sludge should be determined in the field as the sample is bailed, but the rock and mineral determinations may be made either at the drill or in the laboratory.

The final record of drilling which was only referred to above, is kept upon loose leaf sheets which may be filed when completed. For diamond drilling such a sheet is headed with the number of the hole, and the location, dip and course of the hole, and the names of the drillers. There are columns for the date, the number of hours of drilling, the length of the core recovered in feet and inches, the amount of stand pipe in the hole, the number of feet drilled, the total depth of the hole, the kind of material encountered, the depth at which it begins and the dip of the strata. There is also a column for remarks.

Analyses or assay values may be given columns on this same sheet with the report of the drilling, though if the ore contains several metals which must be determined, it may be advisable to make up separate assay sheets.

The final record sheet for the churn drill gives at the top the number and location of the hole, the number of the drill, the distance to permanent water level and the names of the drillers. Columns are given for date, hours drilled, lengths of samples, feet drilled, total depth, and size of casing. There is a column for the kind of material, which is sub-divided giving separate columns for the rock and ore minerals which are checked off for each sample. In addition there are columns for rock names, depth at which formation is cut and the relative amount of concentrates or ore minerals obtained by panning. The extent of alteration of the country rock should also be given a column. Assay values or analyses may be given upon this sheet or a separate record of them may be kept.

It is desirable to have as much as possible of the information for final records shown in some graphic manner. This may be done most conveniently upon tracings from which prints may be made. The rock formation and ore may be indicated by symbols; size of casing and depth are plotted to scale, and a column alongside the plot of the hole is used to give assay values. Prints of such tracings are useful in making reports and the sections of the holes are much easier to study if represented in this way.

APPENDIX

DEFINITIONS

Agglomerate, a loosely cemented mass of fragments derived from the same or different sources. Usually applied to volcanic material.

Alteration, a change in which part of the original material is removed; the term may, but need not necessarily, imply the addition of new material.

Anticline, anticlinal fold, a fold or arch of the rock strata or beds the sides (limbs) of which diverge downward. See Fig. B. Also Folds.

Anticlinorium, a series of folds forming a structural feature which is in its general outline an anticline. Fig. A.

Arenaceous, term applied to rocks made up of sandy material.

Argillaceous, clayey, as for instance argillaceous limestone.

Banded structure, a term applied to vein formation in distinct layers or bands. This may be due to successive periods of deposition, to replacement of some earlier formation, or to movement and sheeting subsequent to deposition.

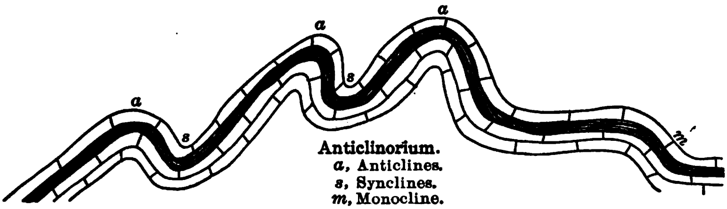


Fig. A.

Batholith, a large rock mass which has solidified at great depth; the rock is coarse in texture due to slow cooling.

Bedded deposit, one which forms a layer or bed of a bedded formation.

Bedded formation, one which shows successive beds, layers, or strata, due to the manner in which it was formed.

Bedding plane, the surface between two successive beds or strata of a bedded formation. It is marked by some slight change in the nature of the material such as a clayey seam between limestone beds.

Boundary, the line dividing two formations of different type or age.

Breccia, a rock formation composed of angular fragments.

Chimney, a term applied to an ore body of much greater vertical extent than its dimensions in horizontal section, which may be roughly circular or elliptical.

Clastic rock, a rock made up of fragmental material from earlier formations.

Clinometer, an instrument for measuring the inclination of beds or veins. See p. 41, Fig. 18.

Closed fold, a fold in which the limbs (sides of the arch) have been compressed until they are parallel. Fig. B.

Conformable, term applied to a later formation the bedding planes of which are parallel with those of an earlier formation. Refer Unconformity.

Conglomerate, a rock composed of waterworn material of various sizes ranging from sand to boulders.

Contact, the line along which an igneous and a sedimentary formation meet—as a "granite-limestone contact." Sometimes more broadly used, especially in underground descriptions to designate any boundary.

Contact deposit, one formed on or near a contact and presumably owing its origin to activities accompanying or following an igneous intrusion.

Contact metamorphism, a general term applied to the changes which take place along a contact—such as recrystallization of limestone, or silicification (producing "flints" or "hornstones"), and the formation of the typical silicate minerals. See page 144.

Country rock, any rock formation which forms the walls of, or encloses an ore deposit.

Cross bedding, a term applied to local variations in the layer structure of sandstones, due to some peculiar current action or local condition during the formation of the bed.

Decomposition, the breaking up of a rock or mineral into its component parts.

Detritus, detrital material, loose material resulting from the weathering and wearing down of a rock formation. Compare Wash.

Dip, the angle which an inclined bed or vein make with the horizontal, measured at right angles to the strike. See p. 41.

Dip fault, a fault the strike of which is parallel to the direction of the dip of faulted strata.

Disseminated deposit, one in which small patches or specs of minerals are scattered irregularly through the rock formation of a considerable area.

Drift, unsorted material transported by a glacier.

Enrichment, the action of natural agencies which increases the metallic content of an ore. Secondary sulphide enrichment refers to the formation of new sulphide minerals which contain a larger percentage of the metals. Refer. Ch. XI.

Erosion, the wearing away of rock masses under the influence of water and wind. Compare Weathering.

Fault, a break in the rock formations accompanied by movement of either of both sides. See p. 95.

Fault scarp, an abrupt steep slope or change of slope due to faulting.

Fissure vein, a common form of ore deposit with well defined walls and roughly tabular shape, the length and vertical extent being great compared to the width. The idea commonly current that a "true fisher (fissure) vein" may extend "right down to the center of the earth" has been discredited in the light of later investigations. It is now recognized that veins and other ore deposits have a fairly definite vertical extent, though it is rarely that mining operations are carried to such depth as to expose the lowest portions.

Flow structure, the traces of movement or currents in rock masses which solidify from a molten condition on the surface of the earth. The lavas before solidification are viscuous or sticky liquids.

Fold, a form of geologic structure resulting from the crumpling or flexing of rock masses.

Foot wall or foot, the lower wall of a fault, vein, or other form of ore deposit.

Gangue, a term applied to the earthy or non-metallic minerals occurring in ore deposits; such as quartz, barite, fluorite, calcite, etc.

Gash vein, a vein which does not extend beyond a certain bed or formation.

Gneissoid, a term applied to rocks of coarse texture which have been crushed or sheared developing bands or laminations.

Gouge, soft clayey material found in faults or veins, resulting from alteration of the country rock and crushing due to subsequent movement.

Granitoid texture, the texture of the granites, gabbros, etc., resulting from the slow cooling of the rock mass and the formation of the minerals without crystal boundaries. See p. 152.

Ground water level, the level at which permanent water is encountered with depth. The water level is not a plane surface but varies with the character of the ground surface, rising somewhat under the hills and often exposed in the valleys except in dry regions.

Hade, the angle which a vein or fault plane makes with the vertical; the complement of the dip. This term has fallen into disuse and the inclination of a fault or vein is read as a dip (inclination from the horizontal).

Hanging wall or hanging, the upper wall of a fault, vein, or other ore body.

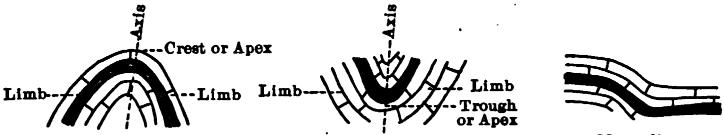
Heave, in describing a fault the heave is the "offset" or shift of an index plane as shown in a horizontal section or plan.

Horse, a mass of barren material, usually country rock, occurring in a vein.

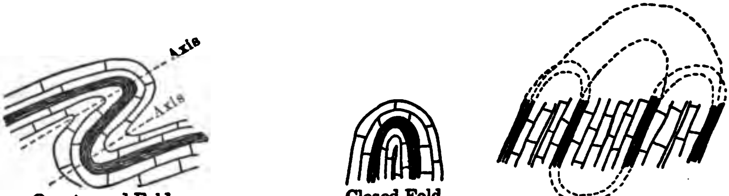
Holocrystalline, a term defining rock texture in which all of the minerals are crystallized.

Igneous, a term applied to agencies involved in or resulting from the formation of rocks from molten masses; also used to designate in a general way the rocks which have resulted from the solidification of molten masses either upon the surface, or in the depths of the earth. Thus we speak of the *igneous origin* of certain ore deposits; periods of *igneous* activity, etc.

Impregnation, the process which results in the general distribution of small mineral particles throughout a rock mass; for instance, "Impregnation of the wall rock with pyrite and other sulphides in small quantities is very common."



Anticline Syncline Monocline



Overturned Folds

Closed Fold

Isoclinal Folds showing Two possible Interpretations of Structure.

Fig. B.

Index plane, a surface of any bed, dike, or vein which may be regarded as a plane and used as a basis for measurements of fault movements.

Intrusion, an igneous rock mass which has been forced into some formation of earlier age.

Isoclinal fold, a closed fold in which the folded beds have the same dip. Often with a series of isoclinal folds the crests of the anticlines have been eroded and the troughs of the synclines cannot be seen so that the true structure is hard to determine. See Fig. B.

Joint, a fracture in a rock mass due usually to cooling from a molten condition, or cooling and cracking from atmospheric changes of temperature.

Kaolinization, the decomposition of certain rock forming minerals to kaolin or clay.

Laccolith, a rock mass of moderate size roughly circular in outline, formed beneath a dome of overlying rocks.

Leaching, the solution and removal of some of the original constituents of a formation.

Lode, a form of ore deposit in which several veins lie close together, so that in places the ground between them is ore-bearing and the entire width may be mined. Compare Vein System.

Magma, a magma is a solution of rock-forming elements. It is an elementary mass in which there has been no crystallization or separation of the rock-forming minerals. See p. 151.

Magmatic differentiation, the separation and grouping of rock-forming elements or minerals, resulting in the development of various rock types from a magma.

Metamorphism, a change in the form or character of the constituents of a rock, which may frequently, but need not necessarily, imply a change of chemical composition due to the addition of new material. Metamorphism may result in the development of gneissoid or schistose structure; or the formation of crystals as in the case of crystallized limestones. In some cases entirely new minerals are formed. Compare Contact Metamorphism.

Metamorphic Rocks, those which have been subjected to changes in texture or chemical composition or both.

Metasomatism means literally the making over of a formation. It is the change in composition through chemical interchange, by which a mineral or aggregate of minerals is partially or completely altered. Replacement is a synonym.

Mineralizers, the vapors held in an igneous magma which are active in the development of minerals. Such gases are steam, hydrofluoric acid, boracic acid, etc.

Monocline, a fold in which the strata have been subjected to a simple flexure, producing dips in one direction only. See Fig. B.

Normal Fault, a fault of which the "hanging," or upper wall, has moved down with respect to the lower wall or "foot."

Oblique Fault, a fault the strike of which makes an angle with the directions of both strike and dip of the faulted formation.

Ore, an ore is any mineral or aggregate of minerals containing one or more of the useful metals and occurring in a natural state in such quantities as to be the object of mining operations.

Pay Ore, is ore which may be mined and treated at a profit under existing conditions.

Non-payable ore is ore which cannot be extracted profitably under existing conditions. For instance, the disseminated copper deposits, containing 1 1/2 per cent. to 2 1/2 per cent. copper, were not recognized as pay ores until a process of concentration had been developed permitting the profitable extraction of the copper. Such ores were, however, the object of unsuccessful mining operations in earlier times.

A gold ore assaying $10.00 per ton might be classed as pay ore in one mine, while in another mine it could not be extracted at a profit owing to less favorable natural conditions, or lack of transportation facilities. Here it would be classed as non-payable. Sometimes the practice prevals of classing as ore all the minerals that may be mined at a profit and calling all material below that grade "rock."

Ore shoot, the richer portion of a vein or other ore deposit. Compare Pay Shoot.

Outcrop, the portion of a formation that is exposed at the surface of the ground.

Overturned Fold, one the limbs of which incline in the same direction. See Fold. Also Fig. B.

Oxidation, the formation of oxides or the conversion of minerals into "oxidized" forms by the addition of oxygen, usually derived from the air.

Oxidized Zone, that portion of an ore deposit which has been subjected to the action of surface waters carrying oxygen, carbon dioxide, etc.

Pay Shoot, a portion of a deposit composed of payable ore.

Phase, (1) any stage or aspect in the development of a given process. For instance, "A different phase of volcanic activity," or "An interesting phase of magmatic differentiation." (2) An appearance or character somewhat at variance with the normal type. For instance, "An extremely silicious phase of the granite magma."

Phenocryst, a crystal formed with complete crystal boundaries.

Plutonic Rocks, those which have cooled in the depths of the earth.

Pneumatolysis, the setting free of vapors from igneous masses and the effects produced by such vapors. Pneumatolytic minerals are those produced through the agency of vapors or gases.

Primary Minerals—primary sulphides—those which retain their original form and composition. Compare Secondary Minerals.

Porphyritic, a rock texture in which separate crystals are prominent, and are surrounded by a mass of finer material.

Pseudomorph, a mineral retaining the form of some earlier mineral which it has replaced.

Replacement, the process by which one mineral or chemical substance takes the place of some earlier different substance, often preserving its structure or crystalline form.

Reverse Fault, a fault of which the "hanging" (upper) wall has moved upward with respect to the "foot" (lower) wall.

Ripple Marks, small ridges or corrugations often seen on the bedding plane surfaces of sandstones or other shallow water sedimentary rocks. These marks are made by wave action and may be seen on beach sands in shallow water.

Scarp, a steep slope, usually formed by the weathering of the up-thrown side of a vertical or steeply dipping fault.

Schistose, a term applied to rocks of fine texture which have been crushed and sheared, so that the original minerals or particles are flattened and elongated, developing thin parallel leaves or laminations.

Secondary Minerals, those which result from the alteration of earlier minerals. Secondary sulphides are those which are made richer in their metallic content by the addition of material resulting from the oxidation of other portions of a deposit. Compare Enrichment. See p. 139.

Segregation, the local gathering or concentration of particles of the same substance.

Sericitization, the development of sericite mica which is frequently encountered in schists and other rocks which have been metamorphosed at considerable depths.

Shear zone, a line along which a rock formation has been crushed and broken or sheeted, but not clearly broken and displaced as by a fault.

Sheeting, the development of small closely spaced parallel fractures.

Sheet, or Sill, a relatively thin, flat, tabular intrusive mass.

Sinter, a porus or cellular encrustation, deposited from hot waters.

Stratification, the layering or bedding of a rock formation due to deposition in successive stages.

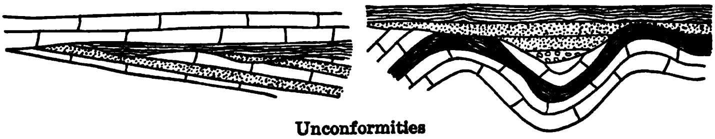


FIG. C.

Striæ, scratches or grooves produced on rock surfaces by faulting or glacial action. Also the parallel bands seen on the cleavage faces of the plagioclase feldspars, caused by twinning in the growth of the crystal.

Strike, the direction of the intersection of a bedding plane, or the plane of a dike, vein, or fault with a horizontal plane.

Stringer zone, a system of small mineralized fractures or stringers having the same general strike.

Structure, those features of geological formations which have to do with their composition or building up on a large scale. Thus folding and stratification are structural features.

Syncline, a fold in which the sides or "limbs" converge downwards forming an inverted arch or trough. See Fig. B.

Synclinorium, a system of folds forming a structural feature of general, synclinomal character. Compare Anticlinorium.

Texture is a term applied to the characteristics of a rock when studied in a detailed way. It refers to the composition of specimens rather than of large masses. For definitions of the different rock textures see p. 151.

Unconformity, a structural feature produced by the deposition of a later formation upon a tilted or partially eroded earlier formation. Fig. C.

Vein, a mineralized fissure; a deposit of slight width compared to its length and vertical extent. It may or may not have well-defined walls.

Vein System, a term applied to the veins of a given area, district, or age, regarded as a whole.

Wash, loose material which has been transported some distance from its source.

Weathering, the changes in a rock formation produced by atmospheric agencies.

Zone, a belt or strip of any formation which is distinguished from the adjoining portions by certain general characteristics.

LISTS OF OUTFITS FOR FIELD WORK

Topographic Mapping and Drafting

Transit.
Level.
Level rod.
Tape, with tension handles.
Thermometer.
Note-books.
Iron rods, for permanent points.
Cement, for setting permanent points.
File, for marking permanent points.
Tin or zinc strips, for marking base line measurements.
Plane table.
Alidade, and striding level.
Stadia rod.
Compass.
Stadia tables.
Scales.
Drawing paper, heavy mounted.
Cover paper, green.
Tracing cloth.
Blue print paper.
White print paper.
Drawing pencils, 6H and 8H.
Soft pencils.
Erasers.
Thumb tacks.
Blank books, for calculations.
Scratch pads.
Inks, colored.
Protractor.
Pens.
Triangle, 60.
Triangle, 45.
Straightedge.
Drawing instruments.
Road pen.
Swivel pen.

For Geologic Mapping

Surface

Small plane table.
Geologist's compass.
Sight alidade.
Small note-book.
Pencils, 6H and 8H.
Protractor.
Scales.
Lens.
Knife with magnetized blades.
Hammer.
Labels, for specimens.
Specimen sack, or shooting vest with large pockets.
Sample sacks.

Underground

Acetylene lamp.
Carbide for lamp.
Water for lamp.
Candles.
Mine map-book.
Small note-book.
Blue or white prints of mine workings.
Geologist's compass.
Scale.
Protractor.
Lens.
Eraser.
Hammer.
Specimen labels.
Specimen sack, or shooting vest with large pockets.
Rope, if examining old workings or abandoned mine.

Personal Outfit, when Camping in the Field or Exploring

Two suits of underwear, woolen for cold weather, light weight flannels otherwise; two flannel skirts; four pairs of heavy socks; one towel; four handkerchiefs; one suit of serviceable clothes; one extra pair of trousers; one pair of heavy shoes, hobnailed (small wood screws, awl, and screwdriver to replace hobnails); one pair of low moccasins, oiled; one felt hat, one cap to sleep in; one pair of suspenders; one belt; one sweater; one comb, one small mirror, safety razor(?), one tooth brush, tooth powder, one cake of soap, toilet paper, buttons, scissors, needles, thread, pins, and safety pins; talc powder (for "foot ease"); poncho or rubber blanket; one light weight rain coat; one canteen; one pocket knife, one sheath knife; compass; fly ointment; fly net; one waterproof match box; one pair of gloves; two pair medium weight woolen blankets, or sleeping bag; writing materials; pack strap.

Don't forget your pipe and tobacco.

Be sure that your boots are in good shape; they should not be absolutely new, but should be "broken in." If they are quite old it is well to carry an extra pair; the weight amounts to little compared to the degree of satisfaction afforded by feet properly shod.

Camp Outfit

(Four men in party)

One 7×9 or 10×12 wall tent. Cooking outfit should "nest" (that is, the different pieces fit inside each other), and should contain: three pots holding six to twelve pints; one coffee pot four pints; four each, cups, bowls, plates, knives, forks, teaspoons; two large spoons, can opener, one basin or gold pan, which may be used for a bread pan. Cloth for dish rags and towels; one camp stove; two pails; two axes; assorted nails; one oil stone; one file; one pair of pinchers; one ball of heavy twine; fifty feet of light rope; one awl handle with set of tools; lanterns, candles, matches in waterproof tube.

Shoe maker's iron last, awl, waxed thread, sole leather, nails, and knife. (Shoemaker's outfit need not be carried unless the trip is a long one.)

Rations

(Four men for two weeks)

Flour 20–25 lb.
Corn meal 6–10 lb.
Beans 6 lb.
Rice 6 lb.
Coffee 6 lb.
Bacon 6 lb.
Ham 10 lb.
New potatoes 16 lb.
or
Dried potatoes 4 lb.
Tea 1 lb.
Fresh biscuit 6 lb.
Oat meal 2 lb.
Butter 5 lb.
Sugar 10 lb.

Baking powder 1 lb.
Condensed milk 5 lb.
Dried fruits 4 lb.
Salt 1 lb.
Chocolate 1 lb.
Pickels 1/2 gal. (5 lb.).
Syrup 1 qt. 2 lb.
1 box pepper.
1 box mustard.
Soap 1 lb.
1 box ginger.
1 box allspice.
6 boxes of sardines.
Raisins 1 lb.
Currants 1 lb.

The ration list given above is intended only as a guide in purchasing supplies, and may be varied to suit individual requirements. If travelling in Mexico with Mexican freighters or miners in the party the bean ration should be increased at the expense of rice or corn meal. It is well, if possible, to hire the natives with the understanding that they furnish their own food.

In a hot dry country the salt and sugar ration should be cut to a minimum, especially if water is scarce.

The compressed or condensed foods, such as dried potatoes, dried eggs, Erbswurst, pemmican, and soup tablets are useful when it is desirable to cut down the weight, but they cannot be obtained at the smaller towns which are usually the outfitting points for field expeditions.

Ordinary canned stuff should not be carried where it is to be packed any distance, for it is weighty and awkward to handle.

Measurement of Gold and Silver Beads by Means of the Microscope

Reference: "The Detection and Estimation of Small Quantities of Gold and Silver." By Luther Wagoner, in Transactions American Institute Mining Engineers, Vol. XXXI, (1901), pages 798 to 810.

The instrument used has an eyepiece with micrometer scale. With the power of 40 diameters, one division is 0.02873 mm.; with 60 diameters one division is 0.02001 mm., which is the power ordinarily used. A clip made of a small watch spring is used to hold the bead, the jaws of the clip should be polished so as to reflect the bead, giving sharp lines for measurement.

The measurements taken are diameter of the bead, diameter of its base, and the height. An approximation to the volume may be obtained by regarding the bead as a portion of a sphere, but the author deduces a formula taking into account the variation from true spherical form, which is as follows:

Weight $= D^3 \times 0.00007598$ for gold (log–5.8807)
and $D^3 \times 0.00004233$ for silver (log–5.6246).
$D =$ number of scale divisions of 0.02001 mm. each

The reader is referred to this paper for a description of the methods of manipulating small beads and assaying for small quantities of the metals.

GUIDE TO THE "SIGHT RECOGNITION" OF ONE HUNDRED AND TWENTY COMMON OR IMPORTANT MINERALS[1]

BY A. J. MOSES

The one hundred and twenty minerals are classified by simple easily used field tests involving only color, streak and approximate hardness as shown by Key page 208.

In each division the minerals are in order of hardness and with the description of each is given the composition and Specific Gravity, and a carefully prepared paragraph in fine type as to occurrence and usual associates.

For confirmation fifty simple tests are described on pages 257 to 265 and the tests appropriate to each species are indicated by numbers after the description of the species.

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[1] Copyright, 1912, by A. J. Moses.

KEY

A. Minerals as Hard or Harder than Quartz.
In order of hardness 7 to 10, pp. 209 to 212.

B. Minerals Softer than Quartz and Colored both in Mass and in Fine Powder (Streak).

1. Both the Mineral and its Streak are **Black** or nearly black, p. 213.
2. The Streak is **Black,** the Mineral is **not Black,** p. 216.
3. The Streak is **Lead-gray or Silver-white,** p. 218.
4. The Streak is **Yellow to Yellowish-brown,** p. 219.
5. The Streak is **Red to Reddish-brown,** p. 222.
6. The Streak is **Green to Blue,** p. 224.

C. Minerals Softer than Quartz and Distinctly Colored in Mass but White in Fine Powder.

1. The Mineral is **Violet, purple or blue,** p. 226.
2. The Mineral is **Green,** p. 228.
3. The Mineral is **Yellow or brown,** p. 233.
4. The Mineral is **Red,** p. 239.
5. The Mineral is **Black,** or nearly so, p. 243.

D. Minerals Softer than Quartz, White or Light Gray in Mass and White in Fine Powder.

1. Will not scratch calcite, p. 246.
2. Will scratch calcite but not fluorite, p. 249.
3. Will scratch fluorite, p. 252.

A. MINERALS AS HARD OR HARDER THAN QUARTZ

Proof.—A pointed fragment of the mineral rubbed back and forth several times with moderate pressure on a smooth quartz surface will leave a scratch which cannot be brushed away.

Sillimanite Al_2SiO_5. H. = 6 to 7. G. = 3.2.

Long almost fibrous orthorhombic prisms and very tough fibrous masses. Color brown or gray. **Tests 32, 50, 28.**

Occurs chiefly in gneiss and crystalline schists. Also as contact mineral in rocks high in alumina. Associates: andalusite, garnet, iolite, corundum.

Spodumene $LiAl(SiO_3)_2$. H. = 6.5 to 7. G. = 3.1 to 3.2.

Broad white or greenish-white plates and monoclinic crystals. Crystals sometimes very large. Rarely transparent, emerald or amethystine crystals. **Tests 29, 50, 38.**

Occurs in granite pegmatites with quartz, feldspars, muscovite, lepidolite, tourmaline, beryl, cassiterite.

Cassiterite SnO_2. H. = 6 to 7. G. = 6.8 to 7.1.

Dull kidney-shaped and rounded pebbles, brilliant tetragonal crystals often twinned, and disseminated grains and masses. Very heavy, brown, reddish and black in color.

Occurs in rocks which have been attacked by boric or hydrofluoric acid. Also in alluvial deposits and sparingly in pegmatites. Associates are topaz, fluorite, tourmaline, scheelite, arsenopyrite, apatite, lepidolite.

Tests 11, 32, 50.

Quartz SiO_2. H. = 7. G. = 2.6.

(*a*) *Vitreous Quartz.*—Glassy hexagonal crystals and glassy shapeless material between crystals of other minerals. VARIETIES: *rock crystal,* if colorless; *amethyst,* if purple to violet; *rose,* if pink; *smoky,* if nearly black; *false topaz,* if brownish-yellow, etc.

(*b*) *Chalcedonic Quartz.*—Translucent crusts and cavity linings with smooth rounded surfaces, often in concentric layers with wax-like luster. VARIETIES: *chalcedony,* if pale colored; *agate,* if mottled, banded, or otherwise varied in color; *carnelian* or *sard,* if brownish-red; *onyx,* if banded dark and white; *chrysoprase,* if apple green, etc.

(c) *Jasper.*—Nearly or quite opaque material, dull and usually of yellow, brown, red and bluish colors. Takes a good polish and contains enclosed much iron and alumina. **Tests 32, 50, 15.**

Occurs as primary constituent of igneous rock, occasionally in distinct crystals, oftener filling residual spaces between other minerals. In metamorphic rocks it occurs as crystals in fissures and disseminated.

Garnet $R_3''R_2'''(SiO_4)_3$. H. = 6.5. to 7.5. G. = 3.1 to 4.3.

Isometric crystals usually dodecahedron or trapezohedron, more rarely glassy grains or masses. Color varying with composition, most frequently a red brown but may be shades of red or black or rarely yellow and green. **Tests 30, 50, 15.**

In almost all rocks, the variety depending on the composition of the rock. Almandite (Fe_3Al_2) is most common in crystalline schists, contacts, gneiss, etc. Pyrope (Mg_3Al_2) is chiefly in olivine and serpentine rocks. Grossularite (Ca_3Al_2) is in contacts in limestone, etc.

Andalusite Al_2SiO_5. H. = 7.5. G. = 3.1 to 3.2.

Coarse square prisms or tough columnar masses. Color pink or pearl gray. **Tests 32, 50, 28.**

Chiefly in clay states as a contact mineral. Less frequently in gneiss, mica schists, etc. Associates: sillimanite, biotite, iolite, garnet, corundum, tourmaline.

Staurolite $Fe(AlO)_4(AlOH)(SiO_4)_2$. H. = 7 to 7.5. G. = 3.6 to 3.75.

Dark Brown to nearly black orthorhombic prisms, often twinned, or in threes, crossing at 90° and 120°. Surfaces bright if unaltered. **Tests 32, 50.**

Chiefly in mica schists and gneiss, rarely in contacts or in granite. Associates: garnet, tourmaline, cyanite.

Tourmaline $R_{18}B_2(SiO_5)_4$. H. = 7 to 7.5. G. = 2.98 to 3.2.

Glassy hexagonal prisms, differently faced at the two ends.

Cross-section often suggests a triangle. Usually black or very dark, sometimes bright reds, greens, blues or browns. **Tests 44, 29, 50.**

In pegmatites or near tin veins and in gneiss, mica schist and clay slate. Very common as contact mineral. Rare as a primary mineral. Associates: quartz, feldspars, beryl, micas, amphibole, cassiterite, etc.

Zircon $ZrSiO_4$. H. = 7.5. G. = 4.7.

Small sharp-cut square prisms, long or short, usually imbedded in the associated mineral. Luster usually adamantine or greasy. Color brown or gray, more rarely colorless, red or greenish. **Tests 32, 50, 15.**

In small amounts in many acid igneous rocks, syenites, granites, diorites. In alluvial deposits and in crystalline limestone. Associates: magnetite, apatite, biotite, titanite, wollastonite.

Beryl $Be_3Al_2(SiO_3)_6$. H. = 7.5 to 8. G. = 2.6 to 2.8.

Hexagonal prisms usually with one plane at end. Color chiefly shades of green or yellow. The deep green variety is the *emerald* and the pale bluish-green variety is the *aqua-marine.* Enormous coarse crystals occasionally found. **Tests 31, 50, 15.**

In contacts and rarely in granites. Also in mica schist and clay slate. Associates: quartz, feldspar, mica, topaz, garnet, tourmaline, etc.

Topaz $Al_{12}Si_6O_{25}F_{10}$. H. = 8. G. = 3.4 to 3.65.

Transparent glassy orthorhombic crystals with rhombic cross sections parallel to which the crystals cleave easily, the cleavage forming often one end of the crystal. Occasionally found as water-worn pebbles and large coarse crystals.

Colorless or pale yellow, less frequently deep brownish yellow or pale blue. **Tests 32, 50, 15.**

Occurs in some granites, pegmatites and rhyolites, and often as contact mineral. Associates: cassiterite, fluorite, beryl, garnet, quartz, feldspar and micas.

Corundum Al_2O_3. H. = 8.5 to 9. G. = 3.95 to 4.1.

Crystals of hexagonal cross section; bluish gray, brownish or white in color and brighter colored gem material which may be blue, "*sapphire*," or red, "*ruby*," or less frequently yellow, green and purple. Also as "*emery*" which is a mixture of corundum with a black iron ore.

Frequently altered to soft material at surface. **Tests 28, 32, 50.**

A primary mineral in igneous rocks rich in feldspar, also in pegmatites, crystalline schists and limestones. Associates: magnetite, nephelite, spinel, chlorite, feldspar.

Diamond C. H. = 10. G. = 3.1 to 3.5.

Isometric crystals often rounded octahedra with luster suggesting oiled glass, and cleaving easily at angles of 70°. Colorless, yellowish and rare bright colors.

Rounded crystallized aggregates without distinct cleavage. Gray to black in color. **Tests 32, 50.**

Occurs in serpentine rocks, hydromica schist, quartzite and alluvial deposits. Associates: garnet, chrysolite, zircon, magnetite, chromite, cassiterite, gold.

B. MINERALS SOFTER THAN QUARTZ AND COLORED BOTH IN MASS AND IN FINE POWDER (Streak)

Proof.—The mineral will not scratch quartz, is colored in mass, and the fine powder made by grinding or rubbing on a piece of unglazed porcelain (streak plate) is not white.

1. Both the Mineral and its Streak are Black or Nearly Black

All the minerals of this division are opaque and either submetallic or metallic in lustre.

Graphite C. H. = 1 to 2. G. = 2.1 to 2.2.

Shining black flakes and masses or dull impure masses. ✓ Soft, greasy and cold to the touch. Will mark paper with shining black STREAK. **Tests 32, 50.**

Chiefly in crystalline schists. Rare in igneous rocks. In limestone contacts with titanite, wollastonite, garnet, spinel, amphibole, pyroxene, etc.

Pyrolusite MnO_2. H. = 1 to 2.5. G. = 4.7 to 4.86.

Bright but easily bruised black needles or radiating fibers or dull black masses. Will mark paper with dull black STREAK. **Tests 6, 32, 46.**

In clays and residual products of decomposed limestones and slates. Associates: other manganese minerals, especially psilomelane, or with limonite or hematite.

Stibnite Sb_2S_3. H. = 2. G. = 4.5 to 4.6.

Dark gray coarsely crystalline or fine grained masses or orthorhombic prisms which cleave into lath-shaped fragments and may be needle like or large. STREAK dark gray to black. **Tests 9, 14, 46.**

Occurs in veins with barite, quartz, cinnabar, etc.

Argentite Ag_2S. H. = 2 to 2.5. G. = 7.2 to 7.6.

Black or dark gray masses, coatings and disseminated material and rarely isometric crystals. It cuts like metallic lead and has shining dark gray STREAK. **Tests 13, 33, 14.**

Occurs in veins with other silver minerals, smaltite, niccolite, etc.

Stephanite, Ag_5SbS_4. H. = 2 to 2.5. G. = 6.2 to 6.3.

Fine-grained, iron-black mineral, often disseminated. Sometimes in short prismatic, orthorhombic crystals. It is soft, but brittle. STREAK black. **Tests 9, 13, 14.**

Occurs in veins with other silver minerals, barite, galenite, etc.

Galenite PbS. H. = 2.5. G. = 7.4 to 7.6.

√ *Very heavy* dark gray masses and isometric crystals which cleave with great ease into cubes of brilliant luster. STREAK dark gray to black. **Tests 16, 14, 33.**

Occurs in ore deposits in igneous rocks and limestone and more rarely as a contact mineral. Associates are: other sulphides, especially sphalerite, pyrite and chalcopyrite, and a gangue of quartz, fluorite, barite or calcite. Also with ores of silver and gold.

Chalcocite Cu_2S. H. = 2.5 to 3. G. = 5.5 to 5.8.

Shining dark gray to black compact masses and disseminated grains. Often coated with the green carbonate of copper. Sometimes in flat (orthorhombic) crystals, sometimes in nodules, sometimes replacing lignite (*wood coal*). STREAK shining dark gray to black. **Tests 42 or 5, 14, 33.**

Occurs as secondary product in ore deposits with other copper minerals, pyrite, hematite, barite and galenite.

Enargite Cu_3AsS_4. H. = 3. G. = 4.4.

Columnar, granular and compact masses and orthorhombic prisms, sometimes radiating. Color brownish-black. STREAK black. **Tests 42, 8, 14.**

Occurs in ore deposits in limestone. Associates: chalcopyrite bornite pyrite, and various arsenates.

Tetrahedrite $Cu_8Sb_2S_7$. H. = 3.5 to 4. G. = 4.5 to 5.1.

Five grained dark gray to black masses and characteristic "tetrahedral" crystals. Sometimes coated with chalcopyrite. STREAK black. **Tests 42, 9, 14.**

Occurs as subordinate mineral in many veins with chalcopyrite, sphalerite, galenite, argentite, siderite.

Wolframite $(Fe.Mn)WO_4$. H. = 5 to 5.5. G. = 7.1 to 7.55.

Heavy black to reddish-drown monoclinic crystals, cleavable, bladed and granular masses. STREAK brownish-black. **Tests 30, 33a, 49,** and the solution becomes deep blue on addition of metallic tin.

In quartz veins in granite and with tin ores. Associates: cassiterite, fluorite, scheelite, quartz, arsenopyrite. Also in alluvial deposits.

Psilomelane MnO_2,BaO,H_2O, etc. H. = 5 to 6. G. = 3.7 to 4.7.

A black massive mineral with structure of limonite; that is, smooth rounded botryoidal or reniform surfaces, or stalactitic. Never crystallized. STREAK brownish-black. **Tests 32, 46.**

Occurs with pyrolusite, other manganese minerals, limonite, barite, etc.

Ilmenite $(Fe.\ Ti)_2O_3$. H. = 5. to 6. G. = 4.5 to 5.

Iron black masses, thin plates, imbedded grains, sand and thick tabular hexagonal crystals. STREAK black. **Tests 32, 7a, 49, 33a.** and the solution boiled with tin becomes violet.

Occurs in large beds and disseminated in igneous and metamorphic rocks. Sometimes in veins. Associates are hematite, magnetite, apatite, rutile, titanite, quartz.

Uraninite UO_3,UO_2,PbO, etc. H. = 5.5. G. = 5 to 9.7.

A black massive mineral of botryoidal or granular structure and pitch-like appearance. Rarely in small isometric crystals. STREAK black. **Tests 32,** and dissolves in nitric acid to a yellow liquid from which ammonia throws down a bright yellow precipitate.

In veins with metallic ores and in pegmatites. Associates: feldspars, rare silicates, ores of lead, silver, copper, alteration products, etc.

Magnetite Fe_3O_4. H. = 5.5 to 6.5. G. = 4.9 to 5.2.

Black, coarse and fine grained masses and sand and well formed octahedral crystals. Strongly attracted by a steel magnet. Sometimes is itself a magnet (lodestone). STREAK black.

Tests 2, 48, 33a.

Occurs in lenticular masses in metamorphic and igneous rocks in disseminated grains, in sand and in contacts. Associates are chlorite, pyrite, chalcopyrite, quartz, feldspars, zircon, apatite, hornblende, pyroxene, mica.

Braunite Mn_2O_3. H. = 6 to 6.5. G. = 4.75 to 4.8.

Brownish-black granular masses and occasional minute tetragonal pyramids almost isometric. STREAK brownish-black.

Tests 32, 6, 48.

Occurs in veins in porphyry and as result of alteration of rhodonite. Associates are: other manganese minerals, barite, hematite.

2. The Streak is Black. The Mineral is not Black

All the minerals of this division are opaque and either metallic or submetallic in luster.

Bornite Cu_5FeS_4. H. = 3. G. = 4.9 to 5.4.

On fresh fracture a peculiar characteristic red bronze color. It tarnishes in blue, purple, and black tints, often variegated. Very brittle and usually massive. STREAK black.

Tests 42, 14, 12, 33a.

Occurs in shale, serpentine rock and pegmatite as an original constituent and with other copper ores. Associates: chalcopyrite, chalcocite, malachite, cassiterite, siderite.

Millerite NiS. H. = 3 to 3.5. G. = 5.3 to 5.6.

A brass colored mineral occurring in hair like or needle crystals or crusts made up of radiating needles. STREAK greenish-black.

Tests 12, 4, 50, 33a.

Occurs in cavities in dolomite, siderite or hematite and incrusting pyrrhotite. Also with chalcopyrite and fluorite.

Chalcopyrite $CuFeS_2$. H. = 3.5 to 4. G. = 4.1 to 4.3.

Compact and granular masses and crystals resembling tetrahedra. Like bright yellow brass, often tarnishing in brilliant peacock colors. Easily cut with a knife and differing in this from pyrite. STREAK greenish-black. **Tests 42, 14, 12, 33a.**

In crystalline schists, in fissures and veins and as contact deposit. Associates: pyrite, copper sulphides, galenite, sphalerite.

Pentlandite (Fe.Ni)S. H. = 3.5 to 4. G. = 4.6 to 5.

Light bronze-yellow granular masses resembling pyrrhotite but not attracted by a steel magnet. STREAK black. **Tests 12, 4, 14, 33a.**

Occurs at Sudbury at contact of quartzite and diorite. Associates: pyrrhotite, chalcopyrite.

Pyrrhotite FeS. H. = 3.5 to 4.5. G. = 4.5 to 4.6.

Compact masses bronze-colored on fresh fracture, tarnishing brown. Powder attracted by a steel magnet. STREAK black. **Tests 12, 14, 46, 33a.**

Occurs in veins, in crystalline schists, near contacts and rarely in igneous rocks. Associates: pyrite, millerite, chalcopyrite, pentlandite, galenite, apatite, molybdenite.

Niccolite NiAs. H. = 5 to 5.5. G. = 7.3 to 7.7.

Color a characteristic pale copper red. Smooth impalpable structure. Sometimes the copper-red kernel has a white metallic crust. Crystals very rare. STREAK black. **Tests 33a, 8, 4.**

In small amounts in igneous rocks and with cobalt, nickel and silver minerals.

Arsenopyrite FeAsS. H. = 5.5 to 6. G. = 6 to 6.2.

Often in tin white granular masses. Also in disseminated crystals, the sections of which are rhombic and rectangular. Strikes fire with steel, and at the same time yields an odor like that of garlic. STREAK black. **Tests 12, 21 or 8, 14.**

In crystalline schists and serpentine and in veins. Associates: quartz, cassiterite, galenite, gold, chalcopyrite, pyrite.

Smaltite $CoAsS$. H. = 5.5 to 6. G. = 6.4 to 6.6.

In cubes or in masses resembling arsenopyrite, though a somewhat darker gray, and often associated with a crimson or pink alteration product. STREAK black. **Tests 3, 12, 21 or 8.**

Occurs in veins with other metallic minerals, especially ores of copper, silver, nickel and cobalt.

Cobaltite $CoAsS$. H. = 5.5. G. = 6 to 6.1.

Silver white to gray masses and pyrite-like crystals. Often a red tarnish. STREAK black. **Tests 3, 12, 21 or 8.**

In crystalline schists and in veins with pyrite, chalcopyrite, molybdenite, galenite.

Pyrite FeS_2. H. = 6 to 6.5. G. = 4.9 to 5.2.

Compact and granular masses, stalactites, nodular concretions with crystal surfaces and isometric cubes, octahedra, and pyritohedra. Color a pale brass yellow. Hard and brittle, striking fire with steel and yielding the odor of burning sulphur. STREAK greenish-black. **Tests 12, 34 or 14, 33a.**

In interbedded often lenticular masses in crystalline schists, in veins, in concretions in clay slates and coal and disseminated. Associates: magnetite, hematite, chalcopyrite, bornite, sphalerite, galenite, etc.

Marcasite FeS_2. H. = 6 to 6.5. G. = 4.6 to 4.9.

Pale brass yellow to almost steel gray orthorhombic crystals. Compound crystals are known as cockscomb pyrites, spear pyrites, etc., from their resemblance to these objects. Often, with radiated structure. Color on fresh fracture is usually whiter than in pyrite, but darkens on exposure. STREAK greenish-black. **Tests 12, 34, or 14, 33a.**

Occurs in sedimentary rocks and in veins with metallic ores, especially sphalerite, galenite and cinnabar.

3. The Streak is Lead-gray or Silver White

These minerals are all opaque and of metallic luster.

Molybdenite MoS_2. H = 1 to 1.5. G. = 4.6 to 4.9.

Graphite-like hexagonal plates, scales and grains of bluish-gray color. Marks paper and is easily cleaved into thin flexible non-elastic plates. STREAK greenish-gray on glazed porcelain.

Tests 41 and soluble in sulphuric acid to a blue solution.

In pegmatites, granite, syenite schist and limestone. Associates: quartz, feldspar, pyrrhotite, cassiterite, wolframite.

Gold Tellurides[1] (Au.Ag) Te_2. H. = 1.5 to 2.5. **G. 7.9 to 9.0.** Steel gray to silver-white minerals, sometimes inclined to yellow. Usually found incrusting or in small veins in the gangue At times in small crystals. STREAK silver-white to gray.

Test 33. The coating on charcoal or the rich ore dropped in boiling concentrated sulphuric acid gives an intense purple coloration.

Occurs in veins and irregular deposits with gold, tetrahedrite, pyrite, molybdenite, fluorite, quartz.

Silver Ag. H. = 2.5 to 3. G. = 10.1 to 11. 1.

Very pale "silver" white when first mined as branching crystals, wire-like filaments, flakes or masses. Tarnishes on exposure, becoming brown to black. Can be cut in shavings, hammered flat or drawn into wire. STREAK silver-white. **Tests 13, 33.**

Occurs in veins or disseminated and with other silver minerals, galenite, pyrite, stibnite, tetrahedrite, etc.

Platinum Pt(Fe). H. = 4 to 4.5. G. = 14 to 19.

Grains, scales and nuggets of steel-gray to white color. Malleable and sometimes attracted by the magnet. STREAK shining steel-gray. **Tests 32, 50, 33a.**

Occurs in alluvial deposits derived from magnesian rocks and associated with gold, iridosmine, chromite, corundum, zircon, diamond, etc. Is said to occur in syenite and is sometimes found included in masses of chromite or of serpentine.

4. The Streak is Yellow to Yellowish Brown

Sulphur S. H. = 1.5 to 2.5. G. = 2.05 to 2.09.

Bright translucent material of resinous luster and color varying from pure sulphur yellow to brown. If impure may be gray. Occurs in rhombic crystals which are exceedingly brittle, and as crusts, stalactites and powder. STREAK pale yellow.

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[1] Sylvanite, Krennerite, Calaverite, Hessite, Petzite.

Tests 34 or 22, 50.

Occurs in sedimentary rocks with gypsum, celestite, calcite, etc. In fissures near active or extinct volcanoes and in small amounts incrusting sulphides of lead, mercury, etc. It is also deposited from hot springs.

Gold Au. H. = 2.5 to 3. G. = 15.6 to 19.3.

Nuggets, grains and scales or distorted crystals passing into wire, leaf and fern-like forms. Color golden yellow to yellowish-white. Very malleable, heavy and soft. STREAK like color.

Tests 33, 50.

Occurs in veins or alluvial deposits or enclosed in other minerals, pyrite, galenite, arsenopyrite, hematite, sphalerite, etc.

Vanadinite $Pb_5Cl(VO_4)_3$. H. = 3. G. = 6.6 to 7.8.

Small, sharp, hexagonal prisms, sometimes hollow, of bright-red, yellow or brown color and resinous luster. Also globular masses. STREAK pale yellow.

Test 16 and with strong nitric acid dissolves to a yellow solution.

In gold and silver veins and with lead ores.

Pyromorphite $Pb_5Cl(PO_4)_3$. H. = 3.5 to 4. G. = 5.9 to 7.1.

Short hexagonal prisms and branching and tapering groups of prisms in parallel position. The color is most frequently green, brown, or gray, and the luster greasy. Also in crusts or with globular moss-like structure. STREAK pale yellow.

Tests 16 and on charcoal fuses to a globule which on cooling does not retain its globular form but crystallizes, showing plane faces.

In lead deposits associated with galenite, cerussite, limonite, malachite, barite.

Siderite $FeCO_3$. H. = 3.5 to 4. G. = 3.8 to 3.9.

In druses or crusts of curved (rhombohedral) six-sided crystals of brown color and glassy luster, and as massive material, with easy cleavage at angles of 107°, or granular. STREAK pale yellow to pale brown. **Tests 12, 35, 46.**

Occurs as beds or concretions in shales especially in the coal formation. More rarely in the crystalline schists and as crystals in the ore deposits. Associates: pyrite, chalcopyrite, galenite, cryolite, etc.

Sphalerite ZnS. H. = 3.5 to 4. G. = 3.9 to 4.1.

"Black jack" or iron-bearing sphalerite occurs as masses and isometric crystals of nearly black color, showing in places usually a yellow to brown. The luster is strongly resinous and the cleavages are at 60° and 90°. STREAK pale brown. **Tests 10, 14, 46.**

Occurs in limestone and in veins with galenite, pyrite, marcasite, siderite, barite, fluorite, dolomite, calcite.

Limonite $Fe_2(OH)_6$, Fe_2O_3. H. = 5 to 5.5. G. = 3.6 to 4.

Varies from brown or yellow loosely compacted "*bog ore*" and "*ochre*" to compact masses often with radiated and stalactitic structure and with nearly black varnish-like surfaces. Never crystallized. STREAK yellowish-brown.

Tests 12, 48, 20, 33a.

In nodules and irregular masses scattered through clays resulting from weathering of ferruginous rocks. Also beds of bog ore precipitated from solution. Associates: manganese ores and iron ores.

Rutile TiO_2. H. = 6 to 6.5. G. = 4.1 to 4.2.

Brownish red to nearly black tetragonal crystals with adamantine luster. Crystals vary from hairs and vertically striated long prisms to thicker square forms and knee-shaped twins and rosettes. Sometimes in crossed or parallel groups of needles. STREAK pale brown. **Tests 7a, 32, 50.**

Common in crystalline schists and contacts. Often as alteration of mica, titanite, ilmenite. Rare as primary in igneous rocks. Associates: quartz, hematite, feldspar, mica.

Cassiterite SnO_2. H. = 6 to 7. G. = 6.8 to 7.1.

(*a*) Dull heavy kidney-shaped and rounded pebbles brown to red in color. (*Stream tin.*)

(*b*) Brilliant heavy brown to black tetragonal crystals. Often square cross sections, sometimes needle-like.

(*c*) Disseminated grains or heavy brown masses sometimes with structure like wood. STREAK pale brown.

Tests 11, 32, 50.

Chiefly in rocks which have been attacked by vapors of boric or hydrofluoric acid. Sparingly in granites and pegmatites. In alluvial deposits. Associates: topaz, fluorite, scheelite, wolframite, arsenopyrite, etc.

Chromite $FeCr_2O_4$. H. = 5.5. G. = 4.3 to 4.6.

A black mineral resembling magnetite but lustre somewhat like pitch. Occurs granular or compact or rarely in small octahedral crystals. Often with serpentine. STREAK dark brown. **Tests 32, 6a, 50.**

Occurs in magnesian rocks and in black sands and platinum deposits. Associates: serpentine, chrome-garnet, platinum.

5. The Streak is Red to Reddish Brown

Erythrite $Co_3(AsO_4)_2.8H_2O$. H. = 1.5 to 2.5. G. = 2.9.

Pink earthy crusts or powder, less frequently minute crimson or peach red crystals. STREAK paler than color.

Tests 8, 3, (20 and turns blue).

Occurs incrusting smaltite, cobaltite and niccolite.

Cinnabar HgS. H. = 2 to 2.5. G. = 8 to 8.2.

Soft and very heavy fine-grained masses with cochineal to dark brownish-red color. Crystalline crusts and disseminated grains. STREAK scarlet. **Tests 23 or 18, 14.**

Filling veins and cavities or disseminated in sandstone or limestone. Associated with pyrite, marcasite, sulphur, barite, opal, quartz.

Proustite Ag_3AsS_3. H. = 2 to 2.5. G. = 5.57 to 5.64.

A scarlet stain or a thin crust with brilliant adamantine luster and a color from scarlet to vermilion. Rare six-sided prisms. STREAK scarlet. **Tests 8, 13, 14.**

Occurs in veins with pyrargyrite, other silver minerals, galenite, etc.

Pyrargyrite Ag_3SbS_3. H. = 2.5. G. = 5.77 to 5.86.

Dark red bands or crusts with a brilliant adamantine luster.

The color often nearly black, but the red tint always showing in thin portions. Rare six-sided prisms. STREAK purplish-red.
Tests 9, 13, 14.

Occurs with proustite in veins with other silver minerals, arsenic, arsenopyrite, galenite.

Copper Cu. H. = 2.5 to 3. G. = 8.8 to 8.9.

The characteristic tough, malleable *red metal.* If tarnished may be deep red, brown or nearly black. Disseminated grains, sheets and irregular masses or groups of extended and branching isometric crystals. STREAK copper red and shining.
Tests 5 or 42.

Occurs in veins or as filling and cement in conglomerate or as alteration of copper minerals. Associates: silver, epidote, calcite, datolite, zeolites.

Bauxite $Al_2O(OH)_4$. H. = 1 to 3. G. = 2.4 to 2.5.

Masses of rounded (oolitic or pisolitic) grains or clay-like. Dull in luster and red to reddish-brown in color. STREAK reddish-brown. **Tests 28, 20, 31.**

Occurs as nodules and irregular lenses in clay or limestone.

Cuprite Cu_2O. H. = 3.5 to 4. G. = 5.8 to 6.1.

Dark red masses with fine-grained almost glassy texture brick red earthy masses; deep red to crimson isometric crystals, sometimes hair-like. STREAK brownish red shining.
Tests 33, 5 or 42.

In upper portions of copper deposits, with limonite, malachite, azurite, copper, chrysocolla.

Tetrahedrite $Cu_8Sb_2S_7$. H. = 3 to 4.5. G. = 4.5 to 5.1.

Fine grained steel-gray masses and tetrahedral crystals *with metallic luster.* STREAK cherry-red. **Tests 42, 9, 14.**

Occurs in many veins with chalcopyrite, sphalerite, chalcocite, gold-telluride, argentite.

Ilmenite $(Fe.Ti)_2O_3$. H. = 5 to 6. G. = 4.5 to 5.

An iron-black mineral of metallic luster, usually massive or in thin plates or imbedded grains or as sand. Rarely in crystals closely like those of hematite in angle. STREAK brownish red.

Tests 32, 7a, 49, 33a.

Occurs in large beds and disseminated in igneous and metamorphic rocks. Sometimes in veins. Associates are feldspars, apatite, quartz, rutile, titanite, serpentine.

Hematite Fe_2O_3. H. = 5.5 to 6.5. G. = 4.9 to 5.3.

Specular Iron.—Black material of very brilliant metallic luster in thin plate-like or rhombohedral crystals and coarse to fine micaceous masses. Occasionally kidney-shaped.

Red Hematite.—Dark red material with little or no luster. May be oölitic, or earthy and ochre-like or fibrous or kidney-shaped. STREAK brownish-red. **Tests 12, 48, 2, 33a.**

In beds in metamorphic rocks, especially the schists. In igneous rocks in crystals and as alteration products of other irons. Associates: magnetite, limonite, siderite, quartz.

6. The Streak is Green or Blue

Chlorite $H_8Mg_5Al_2Si_3O_{18}$(?) H. = 1 to 2.5. G. = 2.6 to 2.9.

Blackish-green to grass green masses of coarse or fine scales. Mica-like crystals with easy cleavage into thin flexible but *non-elastic* plates. Soapy feel. STREAK pale green.

Tests 20, 50, 30.

Occurs in crystalline schists, and as secondary mineral in igneous rocks with garnet, biotite, feldspar, amphibole, pyroxene, serpentine, magnetite.

Garnierite $H_2(Ni.Mg)SiO_4+H_2O$. H. = 2 to 3. G. = 2.27 to 2.8.

Soft loosely coherent material and pea-shaped masses varying from bright green to pale green. Without much luster, but sometimes varnish-like or resinous. STREAK pale green.

Tests 4, 7, 32, 20.

In veins in serpentine with chromite, talc and chrysolite.

Malachite $Cu_2(OH)_2CO_3$. H. = 3.5 to 4. G. = 3.9 to 4.0.

Bright green masses and crusts, often with silky fibrous structure or banded in shades of green. Sometimes stalactitic or botryoidal. Also dull-green, earthy masses, and rarely small, slender, monoclinic crystals. Frequently coating other copper minerals or filling their crevices and seams. STREAK paler green than color. **Tests 5 or 42, 46, 20.**

Occurs in the upper portions of copper deposits and with almost all copper minerals.

Azurite $Cu_3(OH)_2(CO_2)_2$. H.=3.5 to 4. G.=3.8.

Dark blue glassy monoclinic crystals and spherical aggregates and lighter blue crusts and masses sometimes velvety, sometimes dull or earthy. STREAK blue. **Tests 5 or 42, 46, 20.**

Occurs in the upper portions of copper deposits with malachite and other copper minerals.

Uraninite UO_3, UO_2, PbO. etc. H.=5.5. G.=5 to 9.7.

A black massive mineral of botryoidal or granular structure and pitch-like appearance. Rarely in small isometric crystals. STREAK olive green. **Test 32** and soluble in nitric acid to a yellow liquid from which ammonia throws down a bright yellow precipitate.

Occurs in veins with ores of lead, silver, gold and copper. Also in pegmatites with feldspar and rare silicates.

C. MINERALS SOFTER THAN QUARTZ AND DISTINCTLY COLORED IN MASS BUT WHITE IN FINE POWDER

Proof.—The mineral will not scratch quartz, it is colored in mass but the fine powder made by grinding or rubbing on a streak plate is *white.*

1. The Mineral is Violet, Purple or Blue

✓ **Halite** NaCl. H. = 2.5. G. = 3.

Deep indigo blue portions occasionally found in masses of common salt. See page 248. **Tests 37, 35.**

Chalcanthite $CuSO_4.5H_2O$. H. = 2.5. G. = 2.1 to 2.3.

A blue, glassy mineral, with a disagreeable metallic taste. It occurs usually as an incrustation, with fibrous, stalactitic or botryoidal structure; but sometimes in flat triclinic crystals. **Tests 42, 51, 14.**

In mine waters and with chalcopyrite and other copper sulphides, pyrite, copiapite, etc.

✓ **Calcite** $CaCO_3$. H. = 3. G. = 2.7.

Pale blue masses which cleave to rhombohedron with angles of 105°. Occasional bright blue and purple crusts colored by copper or cobalt. **Tests 40, 46, 32.**

In beds and masses in crystalline schists, in sedimentary rocks and filling cavities in igneous rocks and as alteration product of other minerals.

Chrysocolla $CuSiO_3 + 2H_2O$. H. = 2 to 4. G. = 2 to 2.3.

Greenish-blue incrustations and seams, often opal-like in texture. Never found in crystals. **Tests 32, 42, 33, 20, 49.**

In the upper portions of copper deposits.

Barite $BaSO_4$. H = 2.5 to 3.5. G. = 4.3 to 4.6.
Pale blue cleavable and fibrous masses. Not common. See page 249.
Tests 41, 14.

Celestite $SrSO_4$. H. = 3 to 3.5. G. = 4.

Sky blue to pale blue orthorhombic crystals usually tabular or prismatic, and fibrous, lamellar and granularmasses. Cleaves to rhombic plates of 76°.

Occurs in limestones, dolomites, gypsums and shales and in lead veins. Associates: sulphur, gypsum, aragonite, galenite, sphalerite.

Anhydrite $CaSO_4$. H. = 3 to 3.5. G. = 2.9 to 3.

Pale blue cleavable and fine grained masses, cleavage in three directions at 90°. Tests 40, 14, 48.

In beds of rock salt or with gypsum and limestone. Associates: halite, gypsum, calcite.

Aragonite $CaCO_3$. H. = 3.5 to 4. G. = 2.9.
Pale violet tapering crystals not common. See page 251.
Tests 42, 46, 32.

Fluorite CaF_2. H. = 4. G. = 3. to 3.2.

Violet-blue and greenish-blue transparent cubes and masses of glassy luster which cleave in four directions, yielding angles of 109 1/2° and 70 1/2°. Tests 40, 24, 29, 48. ✓

In veins and disseminated in igneous rock and in contacts. Associates: barite, quartz, the metallic ores such as galenite, gold, telluride, cassiterite, etc.

Apatite $Ca_5(Cl.F)(PO_4)_3$. H. = 5. G. = 3.2.
Amethystine and lavender-blue and greenish-blue hexagonal prisms. Sometimes terminated by one face, sometimes by six. Not common. See page 237. Tests 40, 45, 31, 48. ✓

Calamine $(ZnOH)_2SiO_3$. H. = 4.5 to 5. G. = 3.4 to 3.5.
Pale blue druses or compact crusts. Not common. See page 252.
Tests 10, 47, 20.

Smithsonite $ZnCO_3$. H. = 5. G. = 4.3 to 4.5.
Greenish-blue and blue crusts with smooth rounded surfaces. Not common. See page 253. Tests 10, 46

Cyanite Al_2SiO_5. H. = 5 to 7. G. = 3.6 to 3.7.

Sky blue to greenish-blue blade-like triclinic crystals the color deeper along center of blades. Coarsely bladed masses. Cleavage parallel blades. **Tests 32, 28, 50.**

Occurs in crystalline schists with andalusite, staurolite, pyrophyllite, etc., and as alteration of corundum.

Opal SiO_2+nH_2O. H. = 5.5 to 6.5. G. = 2.1 to 2.2.

Pale blue vitreous material, translucent and breaking with shell-like fracture. **Tests 20, 15, 32, 50.**

In cavities and veins of igneous rocks as an alteration product, as concretions in limestone and clay and as deposit from hot springs.

2. The Mineral is Green

Talc $H_2Mg_3(SiO_3)_4$. H. = 1 to 1.5. G. = 2.5 to 2.9.

Pale green foliated masses with soapy feeling. Breaks into non-elastic plates. **Tests 27, 20, 31, 50.**

In crystalline schists, and igneous rock as a secondary alteration of many minerals. Associates: serpentine, magnesite, actinolite, chlorite.

Embolite Ag (Cl.Br). H. = 1 to 1.5. G. = 5.3 to 5.8.

Cerargyrite AgCl. H. = 1 to 1.5. G. = 5 to 5.5.

Thin greenish crusts, darkening in sunlight and cutting like wax. Shining surface after cutting. **Tests 25, 13.**

A distinction is that if heated in a closed tube with acid potassium sulphate, the mineral forms a globule, *cerargyrite* yellow hot, white cold and fused salt is coloress; *embolite* dark red hot, yellow cold and fused salt is yellow.

Occur in upper portions of silver veins with other silver minerals, calcite, barite, limonite.

Chlorite $H_8Mg_5Al_2Si_3O_{18}$?. H. = 1 to 2.5. G. = 2.6 to 2.9.

Grass green to dark green mica-like crystals with pearly luster which cleave to thin, flexible, but not elastic plates. Also masses of coarse to fine scales. **Tests 20, 50, 31.**

Occurs in crystalline schists and as secondary mineral in igneous rocks with garnet, biotite, feldspar, amphibole, pyroxene, serpentine.

Biotite $(H.K)_2(Mg.Fe)_2Al_2(SiO_4)_3$. H. =2.5 to 3. G.=2.7 to 3.1.

Blackish-green apparently hexagonal crystals cleaving easily into thin elastic plates.

In igneous rocks, crystalline schists and contacts.

Chrysocolla $CuSiO_3.2H_2O$. H.=2 to 4. G.=2 to 2.3.

Green enamel-like crusts and seams, compact masses with conchoidal fracture and earthy masses often combined or mixed with some aluminum silicate. **Tests** 42, 32, 49.

Occurs in upper portions of copper deposits with malachite, azurite, limonite.

Serpentine $H_4Mg_3Si_2O_9$. H.=2.5 to 4. G.=2.5 to 2.65.

Masses of dark green, olive green, light green and mottled shades of green and yellow; veins of parallel silky fibers (asbestos) and masses which break in leaves. Luster faint. Feel smooth and greasy. **Tests** 20, 27, 31, 49.

In igneous and metamorphic rocks as an alteration of chrysolite, pyroxene, amphibole, etc. Associates: magnesite, chromite, garnet, garnierite, magnetite, diamond, platinum, etc.

Pyromorphite $Pb_5Cl(PO_4)_3$. H.=3.5 to 4. G.=5.9 to 7.1.

Short hexagonal prisms often parallel. Color bright green to yellowish-green, also rounded masses and moss-like.

Tests 16 and on charcoal fuses to a globule which on cooling shows plane faces or crystal needles.

Occurs in lead veins and beds with galenite, cerussite, limonite, malachite.

Aragonite $CaCO_3$. H. =3.5 to 4. G. =2.9.

Pale green aggregates. Not common. See page 251. **Tests** 42, 46, 32.

Fluorite CaF_2. H.=4. G.=3 to 3.25.

Green and bluish-green transparent glassy cubes and masses which cleave in four directions, yielding angles of 109 1/2° and 70 1/2°. **Tests** 40, 24, 29, 48.

In veins and disseminated in igneous rock and in contacts. With barite, quartz, galenite, gold telluride, cassiterite, wolframite, etc.

Calamine $(ZnOH)_2SiO_3$. H. = 4.5 to 5. G. = 3.4 to 3.5.
Bluish green and pale green crusts with drusy surface. See page 252.
Tests 10, 47, 20.

Smithsonite $ZnCO_3$. H. = 4.5 to 5. G. = 4.3 to 4.5.
Green crusts with smooth rounded surfaces. See page 253
Tests 10, 46.

Apatite $Ca_5(Cl.F)(PO_4)_3$. H. = 5. G. = 3.2.
√ Six-sided prisms terminated by pyramids, bluish-green or sea green with luster of oiled glass. Imperfect cleavage into hexagonal blocks. **Tests 40, 45, 31, 48.**

With metamorphosed limestones, in crystalline schists, in sedimentary rocks and in minute crystals in igneous rocks. Associates: graphite, titanite, magnetite, pyrrhotite, fluorite.

Titanite $CaSiTiO_5$. H. = 5 to 5.5. G. = 3.4 to 3.5.
Pale green and reddish-green wedge-shaped monoclinic crystals, usually small and transparent. **Tests 7a, 30, 49.**

In crystalline limestone and schists and in certain igneous rocks. Associates: albite, chlorite, rutile, apatite, calcite, magnetite.

Enstatite $(Mg.Fe)SiO_3$. H. = 5.5. G. = 3.1 to 3.3.
Olive green to pale green, lamellar to fibrous masses, often with pearly luster. **Tests 31, 50.**

In certain igneous rocks and their alterations with apatite, chrysolite, chondrodite, serpentine.

Pyroxene $RSiO_3$. H. = 5 to 6. G. = 3.2 to 3.6.
Many varieties and usually in crystals (monoclinic) such as:

Diopside $CaMg(SiO_3)_2$ pale green to dark green prisms often with basal parting.

Occur in contacts, limestones and schists with wernerite, vesuvianite, garnet, etc.

Augite CaMgFeAl, etc., blackish-green or lighter in short prismatic crystals, usually eight-sided with angles between *alternate* faces either 90° or near 90° (87° and 93°), not fibrous.
Tests 30, 50, sometimes 12.

Occurs in basic igneous rocks and crystalline limestones, contact rocks, serpentine, etc. Associates: garnet, chlorite, amphibole, wollastonite, magnetite, pyrite, calcite.

Amphibole $RSiO_3$. H. = 5 to 6. G. = 2.9 to 3.4.

Like pyroxene, occurs in many varieties, both monoclinic crystals and fibrous and compact masses. Important are:

Actinolite $Ca(MgFe)_3(SiO_3)_4$ light to dark green in color in bladed non-terminated crystals, divergent fibers and granules.

Occurs in talc and chlorite schists and in contacts. Associates: epidote, talc, serpentine.

Hornblende CaMgFeAl, etc., dark green crystals with rhombic or six-sided cross-section, with angles between adjacent faces near 120° (124° or 116°). **Tests 30, 50, sometimes 12.**

Occurs in contacts, crystalline schists and many other rocks with quartz, feldspar, chlorite, etc.

Wernerite Silicate Na.Ca.Al. H. = 5 to 6. G. = 2.7

Dull green club-shaped tetragonal crystals with eight-sided or square cross-section. (Angles 135° and 90°.) Cleavages at same angles and with faintly fibrous appearance. **Tests 29, 49.**

Occurs chiefly as contacts near limestone. Also in crystalline schists. Associates: pyroxene, apatite, garnet, biotite.

Nephelite (Elæolite) $(NaK)_8\ Al_8Si_9O_{34}$. H. = 5.5 to 6. G. = 2.5 to 2.6.

Translucent grayish-green masses with greasy luster. **Tests 29, 28, 47.**

Found in basic igneous rocks with feldspars, biotite, but not with quartz.

Microcline $K.AlSi_3O_8$. H. = 6 to 6.5. G. = 2.5 to 2.6.

Bluish-green to bright green crystals resembling in shape and habit crystals of orthoclase. Also in masses. Cleavage essentially at right angles (89 1/2°) and often finely striated. **Tests 43, 31, 50.**

Occurs as accessory in many granites. Associates: feldspars, quartz, beryl, topaz.

Cyanite Al_2SiO_5. H. = 5 to 7. G. = 3.6 to 3.7.

Pale green triclinic crystals cleaving easily in one direction parallel largest face. Coarse bladed masses.

Tests 32, 28, 50.

Occurs in crystalline schists with andalusite, staurolite, pyrophyllite, etc.

Opal SiO_2nH_2O. H. = 5.5 to 6.5. G. = 2.1 to 2.2.

Pale green vitreous material breaking with shell-like fracture.

Tests 20, 32, 50.

In cavities and veins of igneous rocks as an alteration product. As concretions in limestone and clay and as deposit from hot springs.

Epidote $Ca_2(Al.Fe)_2(AlOH)(SiO_4)_3$. H. = 6 to 7. G. = 3.2 to 3.5.

A secondary mineral often in and with the original mineral as grains or needles of a peculiar yellowish-green color (pistachio-green). Less frequently in blackish-green monoclinic crystals.

Tests 30, 50, 20.

Occurs in igneous rocks with chlorites, and in metamorphic rocks with amphibole, garnet, feldspar, pyroxene, copper, etc.

Vesuvianite $Ca_6Al_3(OH.F)(SiO_4)_6$. H. = 6.5. G. = 3.3 to 3.4.

Yellowish-green tetrangonal prisms, less frequently pyramidal. Rarely compact, resembling jade. **Tests 30, 50, 20.**

As contact mineral chiefly in limestone, sometimes in serpentines and schist. Associates: garnet, pyroxene, wollastonite, epidote.

Spodumene $LiAl(SiO_3)_2$. H. = 6.5 to 7. G. = 3.1 to 3.2.

Pale green to emerald green monoclinic crystals which split (part) into broad plates. **Tests 36, 29, 38, 50.**

Occurs in cavities in granite with monazite, beryl, and rutile.

Chrysolite $(Mg.Fe)_2SiO_4$. H. = 6.5 to 7. G. = 3.3 to 3.6.

Translucent pale yellowish-green grains, forming masses or sand, or disseminated in volcanic rocks or in other minerals.

Tests 32, 47.

Occurs in lavas and basic igneous rocks with chromite, pyroxene, spinel, garnet, plagioclase.

3. The Mineral is Yellow or Brown

Cerargyrite $AgCl$. H. = 1 to 1.5. G. = 5 to 5.5.

Brownish crusts resulting from action of light on the mineral. Cuts like wax and the cut is shining. **Tests 25, 13.**

In upper parts of silver veins with other silver minerals.

Gypsum $CaSO_4.2H_2O$. H. = 1.5 to 2. G. = 2.3.

Monoclinic crystals and swallow-tail twins of pale yellowish-brown color and transparent. Easily cleavable to a rhombic plate with angle of 66°. Granular masses. **Tests 40, 14, 29, 48.**

In sedimentary deposits with limestones, marl and clay. In beds of rock salt and near volcanic vents. Associates: anhydrite, halite, sulphur, calcite.

Sulphur S. H. = 1.5 to 2.5. G. = 2. to 2.1.

Bright translucent orthorhombic crystals and masses of "sulphur" yellow, less frequently greenish-yellow or yellowish-brown. Impure dull grayish-yellow material. **Tests 34 or 22, 50.**

Occurs in sedimentary rocks with gypsum, celestite, calcite, etc. Also in volcanic fissures and in small amounts incrusting sulphides of lead, mercury, iron, etc.

Halite $NaCl$. H. = 2.5. G. = 2.4 to 2.6.

Common rock salt irregularly brown from visible inclusions. Becomes damp on exposure, has characteristic taste and breaks into cubic fragments. **Tests 37, 35.**

In layers with sedimentary rocks. With gypsum, anhydrite, mirabilite and the chlorides and sulphates.

Muscovite $(HK)AlSiO_4$. H. = 2 to 2.5. G. = 2.8 to 3.

Pearly yellow scales and scaly masses of light yellow or light brown color. Cleaves into thin elastic plates.

Occurs in crystalline schists and limestone and in contacts with feldspar, quartz, tourmaline, beryl, garnet.

Phlogopite $(K.H)_3Mg_3Al(SiO_4)_3$. H. = 2.5 to 3. G. = 2.8.

"Amber mica" in rough prisms with hexagonal or rhombic section, color often bronze-brown darkest near center. Also scales and plates. Cleaves into thin elastic plates which often show six-rayed star by transmitted light if held close to the eye. **Tests 49, 20, 50.**

Occurs in limestone contacts and in serpentine. Associates: pyroxene, amphibole, serpentine.

Cryolite $AlNa_3F_6$. H. = 2.5. G. = 2.9 to 3.

Translucent dull brown material suggesting a brownish wax. **Tests 37, 28, 24, 48.**

Occurs in veins with quartz and disseminated siderite, galenite, chalcopyrite.

Barite $BaSO_4$. H. = 2.5 to 3.5. G. = 4.3 to 4.6.

Heavy masses of brown color and transparent yellow to brown orthorhombic crystals which break into rhombic plates, the rhomb angle being 78 1/2°. **Tests 41, 14, 35, 50.**

Occurs in pockets and lenses in limestone and in the ore veins with galenite, chalcopyrite, fluorite, manganese and iron minerals.

Calcite $CaCO_3$. H. = 3. G. = 2.7.

Very common transparent or translucent pale yellowish-brown hexagonal crystals of many shapes which all cleave to rhombohedra with an angle between faces of 105°. Also in cleavable and granular masses. **Tests 40, 46, 32.**

In beds and masses in crystalline schists, in sedimentary rocks and filling cavities in igneous rocks and as alteration product of other minerals.

Wulfenite $PbMoO_4$. H. = 3. G. = 6.7 to 7.

Thin, square, tabular crystals of yellow, or orange color and resinous luster. Less frequently in granular masses.

Tests 16, 49, and if the solution is greatly diluted, *cooled* and tin added, it becomes deep blue and finally brown.

Occurs in veins with lead ores.

Vanadinite. $Pb_5Cl(VO_4)_3$. H. = 3. G. = 6.6 to 7.2.

Small, sharp, hexagonal prisms, sometimes hollow, of yellow or brown color. Also parallel groups and globular masses of crystals.

Test 16 and with strong nitric acid dissolves to a yellow solution.

Occurs in veins with lead, gold, and silver ores.

Cerussite $PbCO_3$. H. = 3 to 3.5. G. = 6.5 to 6.7.

Impure twinned orthorhombic crystals, often interlaced or in masses of dull yellow or brown color. Very heavy and brittle, and often with galenite. **Tests 16, 46, 50.**

Constitutes the upper portion of some lead deposits and associates are galenite, anglesite, pyromorphite, malachite, limonite.

Serpentine $H_4Mg_3Si_2O_9$. H. = 3 to 4. G. = 2.5 to 2.6.

Masses and silky fibers of dull yellow color. More rarely brown masses. Very little luster. Feel smooth and greasy. **Tests 27, 31, 49.**

In igneous and metamorphic rocks as alteration product of chrysolite, pyroxene, amphibole, etc.

Dolomite $CaMg(CO_3)_2$. H. = 3.5 to 4. G. = 2.8 to 2.9.

Yellowish-brown to dark brown curved rhombohedral crystals. **Tests 40, 27, 46, 32.**

Occurs in cavities and in ore veins.

Pyromorphite $Pb_5Cl(PO_4)_3$. H. = 3.5 to 4. G. = 5.9 to 7.1.

Short hexagonal prism of yellow and yellowish-brown and tapering groups of prisms in parallel position.

Test 16 and on charcoal fuses to a globule which on cooling does not retain its globular form but crystallizes, showing plane faces.

In lead veins and beds with galenite, cerussite, limonite, malachite.

Sphalerite ZnS. H. = 3.5 to 4. G. = 3.9 to 4.1.

Transparent yellow to molasses brown isometric crystals and cleavable masses ("rosin jack"), with strong resinous luster. Also fine-grained. **Tests 10, 14, 46.**

Occurs in fissures or beds in limestone and in veins with galenite, pyrite, marcasite, siderite, barite, fluorite, calcite, or dolomite.

Siderite $FeCO_3$. H. = 3.5 to 4. G. = 3.8 to 3.9.

Curved rhombohedral crystals and masses of light to dark brown color. Cleavage angles of 107°. **Tests 12, 46, 35.**

In beds and concretions in shales, especially in the coal formation. Sometimes in the crystalline schists and as associates of metallic ores, pyrite, chalcopyrite, galenite.

The Zeolites Hydrous Silicates of Na.Ca.Al. H. = 3.5 to 5.5. G. = 2 to 2.4.

Well crystallized "pretty" minerals usually many small crystals forming a crust or lining. Often two or more species in same cavity. **Tests 29, 47 or 48.**

Secondary minerals in rocks which have contained feldspar, leucite, nephelite, etc. They occur in cavities and clefts.

Aragonite $CaCO_3$. H. = 3.5 to 4. G. = 2.9.

Wine yellow to brown orthorhombic simple crystals and pseudohexagonal twinned crystals. Also columnar masses and oölitic. Sometimes transparent. **Tests 40, 46, 35, 32.**

Occurs in cracks and cavities in limestone, dolomite, basalt and in deposits of limonite, siderite and gypsum. Associates: the minerals mentioned sulphur, zeolites, etc.

Fluorite CaF_2. H. = 4. G. = 3 to 3.3.

Transparent wine yellow and rarely brown cubes and masses of glassy luster which cleave into forms of four and eight faces with angles between faces of 109 1/2° and 70 1/2°. **Tests 24, 40, 29, 48.**

In veins and disseminated in igneous rock and in contacts. With barite, quartz, galenite, gold telluride, cassiterite, wolframite, etc.

Scheelite $CaWO_4$. H. = 4.5 to 5. G. = 5.4 to 6.1.

Pale brown masses, square pyramids and drusy crusts. Heavy. **Tests 31, 48** and the salt of phosphorus bead in the reducing flame becomes deep blue, and if powdered and dissolved in dilute hydrochloric acid yields a deep blue solution, on addition of tin.

Occurs in contact zones and in tin veins with cassiterite, wolframite, fluorite, etc.

Calamine $(ZnOH)_2SiO_3$. H. = 4.5 to 5. G. = 4.3 to 4.5.

Pale yellow to pale brown masses, the cavities in which are lined with orthorhombic crystals, often showing only ends, but these usually parallel, forming ridges or combs. The fracture shows the crystals like parallel fibers. **Tests 10, 47, 31, 20.**

Occurs in limestone and clay as secondary mineral with smithsonite, sphalerite, galenite, dolomite, etc.

Smithsonite $ZnCO_3$. H. = 5. G. = 4.3 to 4.5.

Dull brown and rarely bright yellow crusts with smooth rounded surfaces. Occasionally showing hexagonal crystal ends which are three-faced. **Tests 10, 46, 32.**

As precipitation of zinc solutions on or by carbonates. Occurs with sphalerite, calamine, calcite, galenite.

Apatite $Ca_5(Cl.F)\ (PO_4)_3$. H. = 5. G. = 3.2.

Reddish-brown to greenish-brown or yellow, six-sided prisms, often with pyramidal terminations. Luster of oiled glass. **Tests 40, 45, 31, 48.**

With metamorphosed limestone, in crystalline schists, sedimentary rocks, metal veins, and as minute crystals in igneous rocks. Associates: graphite, titanite, magnetite, fluorite, calcite, pyrrhotite.

Titanite $CaTiSiO_5$. H. = 5 to 5.5. G. = 3.4 to 3.5.

Brown or yellow, wedge-shaped or tabular monoclinic crystals, with adamantine or resinous luster. Also compact, massive. Easy cleavages give recognizably monoclinic shapes. **Tests 7a, 30, 49.**

In crystalline limestones and schists and in certain igneous rocks. Associates: albite, chlorite, rutile, apatite.

Monazite $(Ce.La.Di)PO_4$ containing Thorium silicate. H. = 5 to 5.5. G. = 4.9 to 5.3.

In certain sands as yellow to brown rolled grains and as brown monoclinic crystals usually small. **Tests 32, 49, 45.**

Minute crystals in igneous rocks, larger crystals in pegmatites. Also as sand.

Pyroxene $RSiO_3$. H. = 5 to 6. G. = 3.2 to 3.6.

Some thin foliated *diallage* and the somewhat rounded crystals of the variety *Jeffersonite* are brown in color. See page 230. **Tests 30, 50, 12.**

Enstatite $(Mg.Fe)SiO_3$. H. = 5.5. G. = 3.1 to 3.3.

Yellowish-brown fibrous to lamellar masses with pearly luster. **Tests 31, 50.**

In certain igneous rocks and their alterations with apatite, chrysolite, chondrodite, serpentine.

Nephelite (Elæolite) $(NaK)_8Al_8Si_9O_{34}$. H. = 5.5. to 6. G. = 2.5 to 2.6.

Translucent reddish-brown masses and coarse hexagonal crystals, with peculiar greasy luster. **Tests 29, 28, 47.**

In basic igneous rocks with feldspars, biotite, cancrinite, corundum, but not with quartz.

Opal SiO_2nH_2O. H. = 5.5 to 6.5. G. = 2.1 to 2.2.

Ocher yellow, wax yellow and amber brown masses with shell-like fracture. Often with structure of wood. **Tests 20, 15, 32, 50.**

In cavities and veins of igneous rocks as an alteration product. As concretions in limestone and clay.

Orthoclase $KAlSi_3O_8$. H. = 6 to 6.5. G. = 2.4 to 2.6.

Pale yellow masses and monoclinic crystals which cleave in two directions exactly at right angles. The resultant surfaces do not show grooves. **Tests 43, 31, 50.**

Very common in most igneous and many metamorphic rocks. Rare in contacts or sediments. Associates: quartz, micas, other feldspars, epidote, etc.

Vesuvianite $Ca_6Al_3(OH.F)(SiO_4)_6$. H. = 6.5. G. = 3.3 to 3.4.

Brown, square and octagonal prisms and radiated columnar masses. Less frequently in tetragonal pyramids or granular. **Tests 30, 50, 20.**

Occurs chiefly as contact mineral in limestone, sometimes in serpentine and schist. Associates: garnet, pyroxene, epidote, wollastonite.

Epidote $Ca_2(Al.Fe)_2(AlOH)(SiO_4)_3$. H. = 6 to 7. G. = 3.2 to 3.5.

Sometimes the crystals are nearer yellow or brown than green. See page 232.

Sillimanite Al_2SiO_5. H. = 6 to 7. G. = 3.2.

Long fine almost fibrous prisms usually not with terminal planes. Sometimes felted or interlaced masses. **Tests 32, 28, 50.**

In gneiss and crystalline schists, also a contact mineral in rocks high in alumina. Associates: andalusite, garnet, iolite, corundum.

Rutile TiO_2. H. = 6 to 6.5. G. = 4.1 to 4.2.

Reddish-brown to dark brown tetragonal crystals, vertically striated prisms, knee twins and thick square prisms. Sometimes hair-like or massive, or disseminated. **Tests 7a, 32, 50.**

Common in crystalline schists and contacts. Associates: mica, titanite, quartz, hematite, feldspar, chlorite.

Chrysolite $(MgFe)_2SiO_4$. H. = 6.5 to 7. G. = 3.3 to 3.6.

Translucent glassy grains of greenish-yellow color which may exist as sand or in other minerals or as masses. **Tests 32, 47.**

Occurs in lavas and basic igneous rocks with chromite, pyroxene, spinel, garnet, plagioclase.

Cassiterite SnO_2. H. = 6 to 7. G. = 6.8 to 7.1.

Brown kidney-shaped and rounded pebbles (stream tin) dull in luster, very heavy and often with internal structure like wood. Brilliant dark brown tetragonal crystals, often knee-shaped twins and disseminated grains. **Tests 11, 32, 50.**

Chiefly in rocks which have been attacked by vapors of boric acid or hydrofluoric acid. Sparingly in granites and pegmatites. In alluvial deposits. Associates: topaz, fluorite, scheelite, wolframite, arsenopyrite, etc.

4. The Mineral is Red

Gypsum $CaSO_4 2H_2O$. H. = 1.5 to 2. G. = 2.3.

Flesh red or, if impure, brownish-red masses which are made up of pearly scales. Under the glass these are seen to cleave to rhombic plates with angle of 66°. **Tests 40, 14, 29, 48.**

In sedimentary deposits with limestone, marl and clay. In beds of rock salt. With halite, sulphur, calcite, dolomite, etc.

Lepidolite $(KLi)_3Al(SiO_3)_3$. H. = 2 to 2.5. G. = 2.8 to 3.2.
Pink to rose red masses of coarse or fine scales of mica. Each scale with easy cleavage into thinner plates. **Tests 38, 29.**

In tourmaline bearing granites or pegmatites and as rock masses resembling granular limestone. Associates: tourmaline, spodumene, topaz, etc.

Halite NaCl. H. = 2.5. G. = 3.
Occasional red masses with characteristic taste. Color due to impurities. See page 248. **Tests 38, 7, 29.**

Kainite $KCl.MgSO_4.3H_2O$. H. = 2.5 to 3. G. = 2 to 2.2.
Granular sugar-like masses of brownish-red color and disagreeable taste. **Tests 43, 27, 14, 20.**

Most important mineral in Stassfurt potash deposit.

Phlogopite $(KH)_3Mg_3Al(SiO_4)_3$. H. = 2.5 to 3. G. = 2.8.
Brownish-red prisms with hexagonal or rhombic section and also disseminated scales. Cleaves easily into thin elastic plates which often show six-rayed star by transmitted light if held close to the eye.

Occurs in limestone contacts and in serpentine. Associates: pyroxene, amphibole, serpentine.

Barite $BaSO_4$. H. = 2.5 to 3.5. G. = 4.3 to 4.6.
Brownish-red prismatic and tabular orthorhombic crystals cleaving to rhombic plates with angle of 78 1/2°. The red color often superficial. Also compact and cleavable masses.

Occurs in ore deposits especially with iron minerals.

Calcite $CaCO_3$. H. = 3. G. = 2.7.
Pale pink transparent crystals or impure more nearly opaque iron red masses and crystals. Cleavage in three directions at 105° to each other yielding rhombohedron. **Tests 40, 46, 32.**

In beds and masses in crystalline schists, in sedimentary rocks and filling cavities in igneous rocks and as alteration product of other minerals.

Wulfenite $PbMoO_4$. H. = 3. G. = 6.7 to 7.

Orange red, tabular, square crystals with resinous luster. **Tests 16, 49** and if the solution is greatly diluted and stirred up with tin, it becomes deep blue and finally brown.

Occurs in veins with lead minerals.

Vanadinite $Pb_5Cl(VO_4)_3$. H. = 3. G. = 6.6 to 7.2.

Small, sharp, hexagonal prisms, sometimes hollow, of bright-red color. Also parallel groups and globular masses of crystals. **Test 16** and with strong nitric acid the substance dissolves to a yellow solution.

Occurs in gold, silver and lead veins.

Anhydrite $CaSO_4$. H. = 3 to 3.5. G. = 2.9 to 3.

Massive granular material or cleavable in three directions at right angles. Color reddish to brick red. **Tests, 40, 14, 48.**

In beds of rock salt, or with gypsum and limestone. Associates: halite, gypsum, etc.

Serpentine $H_4Mg_3Si_2O_9$. H. = 3 to 4. G. = 2.5 to 2.6.

Brownish red to red (iron-bearing) masses of weak luster and somewhat greasy feel. See page 229. **Tests, 27, 31, 49.**

Aragonite $CaCO_3$. H. = 3.5 to 4. G. = 2.9.

Pink transparent crystals and reddish oölitic masses. See page 251. **Tests 40, 46, 35, 32.**

Sphalerite Zn S. H. = 3.5 to 4. G. = 3.9 to 4.1.

Occasionally the tint of "rosin jack." Passes into a brownish-red. See page 235. **Tests 10, 14, 46.**

Fluorite CaF_2. H. = 4. G. = 3 to 3.2.

Pale rose red eight-faced crystals (octahedra), which cleave parallel to the bounding faces and violet-red cleavable masses. **Tests 24, 40, 29, 48.**

In veins and disseminated in igneous rock and in contacts. With barite, quartz, galenite, gold telluride, cassiterite, wolframite, etc.

Dolomite $CaMg(CO_3)_2$. H. = 3.5 to 4. G. = 2.8 to 2.9.

Cavities in limestone are sometimes lined with numerous small pink rhombohedral crystals with curved edges and faces.

Tests 40, 27, 46, 32.

Often chief constituent of sedimentary rocks. Also in beds and masses in crystalline schists and in veins.

The Zeolites. Hydrous Silicates of Na,Ca and Al. H. = 3.5 to 5.5. G. = 2 to 2.4.

Usually well crystallized pretty minerals often by union of many crystals forming an incrustation.

Tests 29, 47 or 48 usually.

Occur in cavities of rocks containing feldspars, leucite, nephelite, etc.

Apatite $Ca_5(Cl.F)(PO_4)_3$. H. = 5. G. = 3.2.

√ Hexagonal prisms often with pyramid terminations red, brownish-red or mottled with green. The luster resinous or like oiled glass. Imperfect cleavage into hexagonal blocks.

Tests 40, 45, 31, 48.

With metamorphosed limestones in crystalline schists, in sedimentary rocks, and in minute crystals in igneous rocks. Associates: graphite, titanite, magnetite, pyrrhotite, etc.

Wernerite Silicate NaCaAl. H. = 5 to 6. G. = 2.7.

Columnar or fine grained aggregates often with good prismatic cleavage. Color red-violet. See page 254. **Tests 29, 49.**

Monazite (Ce.La.Di) PO_4. H. = 5 to 5.5. G. = 4.9 to 5.3.

Small brownish-red monoclinic crystals. **Tests 32, 49, 45.**

Occurs in igneous rocks and in pegmatites.

Nephelite (Elæolite)$(NaAl)_8 Si_9O_{34}$. H. = 5.5 to 6. G. = 2.5 to 2.6.

Translucent brownish-red to brick-red masses and coarse hexagonal crystals with peculiar greasy luster.

Tests 29, 28, 47.

In basic igneous rocks with feldspars, biotite, corundum, but not with quartz.

Plagioclase $n\text{NaAlSi}_3\text{O}_8+m\text{CaAl}_2\text{Si}_2\text{O}_8$. H. = 5 to 7. G. = 2.6 to 2.7.

Flesh-colored or brownish-red masses which cleave in two directions *nearly* at right angles and usually show parallel grooves (striations) on the cleavage surfaces.

Tests 37, 50, 31, sometimes 29.

Very common in igneous rocks and crystalline schists. Associates: quartz, orthoclase, mica, garnet and tourmaline.

Orthoclase KAlSi_3O_8. H. = 6 to 6.5. G. = 2.4 to 2.6.

Pink to flesh-colored and red masses and monoclinic crystals often twinned. Easy cleavages in two directions at right angle which yield smooth ungrooved surfaces. **Tests 43, 31, 50.**

Very common in most igneous and many metamorphic rocks. Rare in contacts or sediments. With quartz, other feldspars, mica, epidote, etc.

Rutile TiO_2. H. = 6 to 6.5. G. = 4.1 to 4.2.

Dark reddish-black tetragonal crystals with brilliant luster or brighter red needles often parallel or netted. **Tests 7a, 32, 50.**

In crystalline schists and contacts, or as alteration of mica, titanite, ilmenite. Associates: quartz, hematite, feldspar, mica.

Opal $\text{SiO}_2\text{nH}_2\text{O}$. H. = 5.5 to 6.5. G. = 2.1 to 2.2.

Transparent or translucent material with red and yellow reflections (fire opal), or more opaque jasper-like masses with glassy luster and dark-red color. **Tests 20, 15, 32, 50.**

In cavities and veins of igneous rocks as an alteration product. As concretions in limestone and clay and as deposit from hot springs.

Epidote $\text{Ca}_2(\text{AlFe})_2\text{AlOH}(\text{SiO}_4)_3$. H. = 6 to 7. G. = 3.2.

Grains, needles and small monoclinic crystals of violet-red color. See page 232. **Tests 30, 50, 20.**

5. The Mineral is Black or Nearly So

Biotite $(\text{H.K})_2(\text{Mg.Fe})_2\text{Al}_2(\text{SiO}_4)_3$. H. = 2.5 to 3. G. = 2.7 to 3.1.

Disseminated scales and plates with characteristic easy cleavage of mica to elastic plates. Less frequently moderate sized pseudohexagonal crystals. Luster pearly to submetallic.

Very common in igneous rocks, crystalline schists and contacts.

Calcite $CaCO_3$. H. = 3. G = 2.7.
Occasionally black from impurities and then massive fine grained or with shelly structure. See p. 249. **Tests 40, 46, 32.**

Serpentine $H_4Mg_3Si_2O_9$. H. = 3 to 4. G. = 2.5 to 2.65.
Greenish-black compact masses with little luster and smooth somewhat greasy feel. **Tests 27, 31, 49.**

Occurs in igneous and metamorphic rock as alteration product. Associates: magnesite, chromite, garnet, etc.

Dolomite CaMg $(CO_3)_2$. H. = 3.5 to 4. G. = 2.8 to 2.9.
Black crystals (rhombohedron and base) and some impure massive varieties. See page 250. **Tests 40, 27, 46, 32.**

Fluorite CaF_2. H. = 4. G = 3 to 3.3.
Small cubic crystals with octahedral cleavage. See page 236.
Tests 24, 40, 29, 48.

Andalusite (Chiastolite) H. = 3 to 7.5. G. = 3.2.
Coarse rounded prisms, cross sections of which show a cross or checked figure, due to the symmetrical deposition of the impurities.

In clay slates as a contact mineral, also in gneiss, mica, schists, etc. Associates: sillimanite, biotite, garnet, corundum, tourmaline.

Titanite $CaTiSiO_5$. H. = 5 to 5.5. G. = 3.4 to 3.5.
Black distinctly monoclinic crystals with brilliant luster and easy cleavages. **Tests 7a, 30, 49.**

In crystalline limestones and schists and in certain igneous rocks. Associates: albite, chlorite, rutile, apatite, calcite.

Pyroxene (Augite) $RSiO_3$. (R = CaMgFeAl). H. = 5 to 6. G. = 3.2 to 3.6.

Usually short prismatic monoclinic crystals with eight-sided cross section with angles between alternate faces 90° or 87°. **Tests 12, 50.**

In lavas and basic igneous rocks. Less common in metamorphic rocks and contacts. With amphibole, garnet, calcite, magnetite.

Amphibole (Hornblende) $RSiO_3$. R = (CaMgFeAl). H. = 5 to 6. G. = 2.9 to 3.4.

Short prismatic monoclinic crystals with six-sided cross section, the angles being 124° and 116°. Also in long blade-like and fibrous masses with luster of horn. **Tests 12, 50.**

In igneous and metamorphic rocks and as contact mineral, with feldspars, quartz, pyroxene, chlorite.

Hypersthene $(Mg.Fe)SiO_3$. H. = 5 to 6. G. = 3.4 to 3.5.

Black foliated masses and cleavable aggregates sometimes with copper red iridescence and usually with pearly almost metallic luster. Rare orthorhombic crystals. **Tests 30, 12, 49.**

Occurs in basic igneous rocks with plagioclase (labradorite), chrysolite, amphibole, magnetite, titanite, not with quartz.

Rutile TiO_2. H. = 6 to 6.5. G. = 4.1 to 4.2.

Nearly black rosettes and tetragonal crystals and masses with submetallic luster. **Tests 7a, 32, 50.**

In crystalline schists, and contacts, or as alteration of mica, titanite, ilmenite. Associates: quartz, hematite, feldspar, mica.

In crystalline schists and contacts, or as duration of mica, titanite, elements. Associates: quartz, hematite, feldspar, mica.

Cassiterite SnO_2. H. = 6 to 7. G. = 6.8 to 7.1.

Tetragonal crystals with brilliant luster, sometimes needle-like. Often twinned. **Tests 11, 32, 50.**

Chiefly in rocks which have been attacked by vapors of boric acid or hydrofluoric acid. Sparingly in granite and pegmatites. In alluvial deposits. Associates: topaz, fluorite, scheelite, wolframite, arsenopyrite, etc.

D. MINERALS SOFTER THAN QUARTZ WHITE OR LIGHT GRAY IN MASS AND WHITE OR LIGHT GRAY IN FINE POWDER

(This would include colorless and *very* pale tints.)

Proof.—The mineral will not scratch quartz, it is white or light gray in mass and the fine powder, made by grinding or rubbing on a streak plate, is white.

1. Will not Scratch Calcite

Ulexite $CaNaB_5O_9.8H_2O$. H. = 1. G. = 1.65.

White, rounded masses (cotton-balls) of loosely-compacted, intertwined, silky fibers, which are easily pulverized between the fingers. **Tests 29, 37, 44, 48.**

In lagoons and troughs alternating with layers of salt, with borax as incrustation of "lake" and embedded in gypsum.

Asbestos. Apparent hardness 1 to 2.5.

White fibrous varieties of amphibole and serpentine, though really belonging page 254 or 229.

Tripolite. Apparent hardness 1 to 2.5.

White porous chalk-like variety of opal actually harder than glass. See page 255.

Chalk. Apparent hardness 1 to 2.5.

White loosely coherent masses $CaCO_3$. See page 249.

Talc $H_2Mg_3(SiO_3)_4$. H. = 1 to 1.5. G. = 2.5 to 2.9.

A very soft gritless material with soapy feeling. Occurs foliated, with pearly luster or fine-grained or wax-like. Will cut without crumbling. Color white or gray.

Tests 20, 27, 31, 50.

Occurs in crystalline schists and igneous rock as an alteration product of many minerals. Associates are: serpentine, magnesite, dolomite, actinolite, chlorite.

Cerargyrite $AgCl$. H. = 1 to 1.5. G. = 5 to 5.5.

Usually thin gray crusts which look and cut like horn or wax. Luster resinous. **Tests 25, 13.**

In upper parts of silver veins with other silver mineral.

Soda Niter $NaNO_3$. H. = 1.5 to 2. G. = 2.2 to 2.3.

Usually fine-grained white or grayish masses which become damp on exposure and have the so-called "cooling " taste. **Tests 26, 37.**

Occurs in high planes of Andes about 6 to 10 ft. below surface in enormous beds.

Mirabilite $Na_2SO_4.10H_2O$. H. = 1.5 to 2. G. = 1.5.

Translucent, white, fibrous crusts or monoclinic crystals, closely resembling those of pyroxene in form and angle. On exposure loses water and falls to powder. Taste bitter. **Tests 51, 37, 14.**

In solution and in mud of bottom of "dry lakes" with halite, gypsum, etc.

Gypsum $CaSO_4.2H_2O$. H. = 1.5 to 2. G. = 2.3.

Fine-grained compact gray *rock gypsum.*

Transparent colorless monoclinic crystals and plates of *selenite* cleaving to a rhomb of 66°, white silky fibrous *satin spar* or fine compact *alabaster.* **Tests 40, 14, 20, 29, 48.**

In sedimentary deposits with limestone, mud and clay. In beds of rock salt and near volcanoes. With halite, sulphur, calcite, dolomite, etc.

Kaolinite $H_4Al_2Si_2O_9$. H. = 2 to 2.5. G. = 2.6. Dull white clay-like or mealy masses which become highly plastic. Minute scales of pearly luster, flexible but not elastic. Greasy feel. **Tests 28, 32, 50.**

Occurs in beds and in ore veins with quartz, feldspar, corundum, etc.

Muscovite $(H.K)AlSiO_4$. H. = 2 to 2.5. G. = 2.8 to 3. Silvery gray plates and masses of scales and crystals, often large and rough, with rhombic or hexagonal cross-section.

Luster pearly, cleavage very easy into thin elastic plates. Masses of fine pearly white scales. **Tests 31, 50, sometimes 20.**

Common in pegmatites and certain granites as primary mineral common in crystalline schists and contacts. Often secondary (sericite) by alteration of feldspars and other micas. Associates: feldspar, quartz, beryl, garnet.

Lepidolite $(K_1Li)_3Al(SiO_3)_3$. H. = 2 to 2.5. G. = 2.8 to 3.2. Short prisms of pearly luster and gray color and pinkish-white masses of fine scales. Easy cleavage into thin elastic plates.

Occurs in granite and pegmatites. Associates: tourmaline, spodumene, cassiterite, topaz.

Borax. $Na_2B_4O_7.10H_2O$. H. = 2 to 2.5. G. = 1.7. Glistening white crusts or translucent monoclinic crystals which become snow white. Taste alkaline. **Tests 44, 37, 20, 36.**

Occurs in muddy bottoms of certain marshes and lakes.

Halite. NaCl. H. = 2.5. G. = 2.4 to 2.6. Masses which cleave to cubes and have the characteristic taste of common salt. Isometric crystals often with hollow faces. Becomes damp on exposure. **Tests 37, 35.**

In layers with sedimentary rocks. In solution as brines in pores of rock or in sea water. Associates gypsum, anhydrite, and the soluble chlorides and sulphates.

Cryolite $AlNa_3F_6$. H. = 2.5. G. = 3. Translucent snow white to gray masses resembling frozen snow. Rarely small six-sided monoclinic crystals nearly cubes. **Tests 37, 28, 24, 29.**

Occurs in veins with quartz and with disseminated siderite, galenite, chalcopyrite, etc.

Kainite $KCl.MgSO_4.3H_2O$. H. = 2.5 to 3. G. = 2 to 2.2. Granular sugar-like masses with disagreeable bitter taste. **Tests 43, 27, 14, 20.**

Occurs in potash deposit at Stassfurt, Prussia, as secondary mineral with halite, carnallite, etc.

Bauxite $Al_2O(OH)_4$. H. = 1 to 3. G. = 2.4 to 2.5.
White to gray masses of rounded grains (pisolites or oölites) or earthy and clay-like. No luster. **Tests 28, 20, 32.**

Occurs in nodules and lenses in clay and in beds above clay or in limestone and dolomite.

Anglesite $PbSO_4$. H. = 3. G. = 6.1 to 6.4.
Simple orthorhombic prisms often transparent and colorless, white brittle masses and compact granular masses of gray color from intermixed galenite. **Tests 16, 14, 50.**

Occurs in cavaties in galenite and in upper parts of lead deposits. Associates: galenite, cerussite.

Barite $BaSO_4$. H. = 2.5 to 3.5. G. = 4.3 to 4.6.
Colorless white and gray prismatic and tabular orthorhombic crystals, cleaving to rhombic plates with angles of 78 1/2°. Cleavable, granular and compact masses. Cockscomb groups. **Tests 41, 14, 35, 50.**

Occurs in pockets or lenses in limestone and in ore veins with galenite, sphalerite, fluorite, chalcopyrite, manganese minerals, etc.

Celestite $SrSO_4$. H. = 3 to 3.5. G. = 3.9 to 4.
Colorless to white orthorhombic crystals. Very similar to barite. Less often in large masses, often shows a pale blue tinge. Angle of cleavage rhomb 76°. **Tests 39, 14, 29, 50.**

Occurs in sedimentary rocks and limestone or gypsum. Associates: gypsum calcite, sulphur, etc.

2. Will Scratch Calcite but not Fluorite

Barite, anglesite and celestite above described as well as unusually hard specimens of *bauxite* and *kainite* may work out in this division.

Calcite $CaCO_3$. H. = 3. G. = 2.7.
Transparent and translucent hexagonal crystals of many shapes, chiefly scalenohedra and rhombohedra, all of which will cleave into rhombohedra, the angle between adjacent cleavages

being 105°. Also granular masses, stalactites and oölitic material. Foliated and fibrous masses rare.

Tests 40, 46, 32.

In beds and masses in crystalline schists, in sedimentary rocks and filling cavities in igneous rocks and as alteration product of other minerals.

Anhydrite $CaSO_4$. H. = 3 to 3.5. G. = 2.9 to 3.

Fine grained or lamellar white and gray masses. Colorless or gray cleavable masses, cleaving in three directions at right angles. Rare small prismatic orthorhombic crystals.

Tests 29, 40, 14, 48.

Occurs in beds of rock salt, in limestone and shales. Associates: halite, gypsum.

Pyromorphite $Pb_5Cl(PO_4)$. H. = 3.5 to 4. G. = 5.9 to 7.1.

Groups of small hexagonal prisms in parallel position and gray or pinkish-gray in color. **Test 16** and on charcoal fuses to a globule which on cooling is crystalline.

In lead veins and beds with galenite, cerussite, limonite, malachite.

Cerussite $PbCO_3$. H. = 3 to 3.5. G. = 6.5 to 6.6.

Gray translucent masses very heavy and with adamantine luster on fresh fracture.

Colorless, white and gray orthorhombic crystals often star-shaped or with satin-like luster from twinning. Also milk white fibers and bundles often interlaced. **Tests 16, 46, 50.**

Occurs in upper portion of lead deposits sometimes in large quantities. Associates: galenite, limonite, malachite.

Apatite (Phosphate Rock) $Ca_3F(PO_4)_3$. H. = 2 to 5. G. = 3. 1 to 3.2.

Impure white to gray masses or nodules and kidney shaped material. Occurs in beds and in concretions. **Tests 40, 45.**

Dolomite $CaMg(CO_3)_2$. H. = 3.5 to 4. G. = 2.8 to 2.9.

Small curved rhombohedral crystals, usually lining a cavity or incrusting some other mineral. Also in coarse or fine grained masses. Cleaves to rhombohedron with 106° between adjacent faces. **Tests 40, 27, 46, 32.**

Often chief constituent of sedimentary rocks, also as beds and masses in crystalline schists and in the ore veins.

Magnesite $MgCO_3$. H. = 3.5 to 4.5. G. = 3 to 3.12.

Compact, snow-white material like unglazed porcelain with marked rounded shell-like fracture. More rarely chalk-like. Not often in crystals. **Tests 27, 46, 32.**

Occurs as veins in sepentine or beds like limestone or disseminated in talcose or chloritic schists.

Siderite $FeCO_3$. H. = 3.5 to 4. G. = 3.83 to 3.88.

Compact fine-grained gray masses, often brown externally. **Tests 12, 46, 35.**

In beds and concretions in shales especially in the coal formation. Sometimes in the crystalline schists and as associate of metallic ores, pyrite, chalcopyrite, galenite.

Andalusite (Chiastolite) (Al_2SiO_5). H. = 3 to 6. G. = 3.2.

Coarse, rounded prisms, cross-sections of which show a cross or checked figure, due to the symmetrical deposition of the impurities. Color white or gray. **Tests 32, 28, 50.**

In clay states as a contact mineral, also in gneiss mica schists, etc. Associates: sillimanite, biotite, garnet, corundum, tourmaline.

Aragonite $CaCO_3$. H. = 3.5 to 4. G. = 2.9.

Snow white, coral-like, *flos ferri*, and fibrous crusts, white to gray 'orthorhombic crystals, sometimes needle prisms. Also pseudohexagonal twins. **Tests 40, 46, 35, 32.**

Occurs in iron deposits in cavities in limestone and deposited from hot springs. Associates: limonite, siderite, sulphur, zeolites, serpentine.

Sphalerite. ZnS. H. = 3.5 to 4. G. = 3.9 to 4.1.
Occasionally found as a white powder.

The Zeolites. Hydrous silicates Na,Ca.Al. H. = 3.5 to 5.5. G. = 2 to 2.4.

Well crystallized, pretty minerals often colorless or white, usually many small crystals forming a crust or lining. Often two or more species together.

Secondary minerals in rocks containing feldspar, leucite, nephelite, etc.

3. Will Scratch Fluorite

Magnesite and the zeolites just described may work out in this division.

Fluorite CaF_2. H. = 4. G. = 3. to 3.2.

Cubic crystals and masses of glassy luster which break in four directions at angles of 109 1/2° or 70 1/2°. In some white massive varieties the cleavage is not good. **Tests 24, 40, 29, 48.**

Occurs in veins and disseminated in igneous rocks and as a common gangue of metallic ores especially galenite, gold telluride, sphalerite, cassiterite. Quartz and barite are often associated.

Colemanite $Ca_2B_6O_{11}.5H_2O$. H. = 4 to 4.5. G. = 2.2 to 2.5.

Transparent, colorless, highly modified, monoclinic crystals. Compact white porcelain-like masses and loosely compacted chalk-like masses. **Tests 44, 28, 29, 48.**

Occurs in beds interstratified with sediments or underlying gypsum. Associates: gypsum, celestite, quartz.

Wollastonite $CaSiO_3$. H. = 4 to 5. G. = 2.8 to 2.9.

White or grayish fibrous to silky masses and tabular cleavable monoclinic crystals. Usually intermixed with calcite. **Tests 31, 47, 40.**

Occurs in limestone as contact mineral, rarely in other rocks rich in calcium. Associates: garnet, pyroxene, vesuvianite, graphite.

Calamine $(ZnOH)_2SiO_3$. H. = 4.5 to 5. G. = 3.4 to 3.5.

Brownish-white or gray masses and crusts with drusy surface sometimes forming ridges, because of parallel position of crystals. When broken the fracture shows the grouped crystal-like fibers at right angles to drusy surface. Less frequently colorless transparent orthorhombic crystals thin tabular and differently developed at the two ends. **Tests 10, 47, 31, 20.**

Occurs in limestone and clay as secondary mineral with smithsonite, sphalerite, galenite, dolomite, etc.

Smithsonite $ZnCO_3$. H. = 5. G. = 4.3 to 4.5.

Brownish-white or gray masses with smooth rounded surfaces sometimes suggesting chalcedony. Porous cellular masses and rarely "drusy" surfaces, the hexagonal crystal ends being three-faced. **Tests 10, 46, 32.**

Occurs with other zinc minerals calamine, sphalerite, etc., or frequently replacing calcite.

Apatite $Ca_5(ClF)(PO_4)_3$. H. = 4.5 to 5. G. = 3.2.

Dull white six-sided hexagonal prisms with pyramid ends or compact bone-like masses. Rarely colorless crystals.

Tests 40, 45, 31, 48.

With metamorphosed limestones in crystalline schists, in sedimentary rocks, and in minute crystals in igneous rocks. Associates: graphite, titanite, magnetite, pyrrhotite, etc.

Scheelite $CaWO_4$. H. = 4.5 to 5. G. = 5.9 to 6.1.

Translucent grayish- to yellowish-white masses and tetragonal pyramids. Very heavy.

Tests 31, 48, and salt of phosphorus bead in the reducing flame becomes deep blue, and powdered and dissolved in dilute hydrochloric acid yields a deep blue solution, on addition of tin.

Occurs in contact zones and in tin veins with cassiterite, wolframite, fluorite, etc.

Pyroxene (Diopside) $CaMg(SiO_3)_2$. H. = 5 to 6. G. = 3.2 to 3.6.

Greenish-white and colorless and dull yellowish-white monoclinic crystals often showing parting parallel the base. Cross-section four or eight-sided, four of the sides constituting a rectangle, the alternate four a rhomb with angle of 87°. Not fibrous.

Tests 29, 50.

Some of aluminous varieties as *leucaugite* are also white.

Occurs in crystalline limestone, contact rocks, igneous rocks, crevices in chlorite or hornblende schists, serpentine, etc. Associates: garnet, chlorite, magnetite, pyrite, calcite, amphibole, wollastonite, etc.

Amphibole (Tremolite) $CaMg_3(SiO_3)_4$. H. = 5 to 6. G. = 2.9 to 3.4.

White or gray in color. Blade-like crystals with cross-section, a rhomb of 124°. Rarely thick, vertically striated crystals with six-sided cross-section. Columnar or fibrous masses, the fibers parallel or radiating or interlaced. Cleavage at 124°. Luster silky or glassy.

Occurs as contact mineral in crystalline schists and limestones. Associates: tourmaline, pyroxene, chlorite.

Enstatite $(Mg.Fe)SiO_5$. H. = 5.5. G. = 3.1 to 3.3.

Pale gray masses with fibrous structure and often pearly luster.

Tests 31, 50.

In certain igneous rocks and their alterations with apatite, chrysolite chondrodite, serpentine.

Wernerite Silicate of NaCaAl. H. = 5 to 6. G. = 2.7.

Pearl gray to white. Coarse thick club-shaped tetragonal crystals. Octagonal or square cross-section (angles 135° or 90°). Sometimes rounded. Cleavages with same angles and faintly fibrous appearance. Also columnar or granular aggregates.

Tests 29, 49.

Chiefly a contact mineral near limestone, also in crystalline schists. Associates: pyroxene, garnet, amphibole, mica, wollastonite, titanite.

Nephelite (Elæolite) $(NaAl)_8Si_9O_{34}$. H. = 5.5 to 6. G. = 2.5 to 2.6.

Translucent greenish-gray or bluish-gray masses with peculiar greasy luster. **Tests 29, 28, 47.**

In basic igneous rocks with feldspar, biotite, corundum, but not with quartz.

Leucite $KAl(SiO_3)_2$. H. = 5.5 to 6. G. = 2.4 to 2.5.

Isometric (trapezohedra) crystals and round grains in volcanic rocks, translucent to nearly opaque. **Tests 32, 28, 49.**

Occurs only in igneous rocks and chiefly in lavas.

Cyanite Al_2SiO_5. H. = 5 to 7. G. = 3.6 to 3.7.

Colorless white or grayish blade-like crystals and aggregates often blue in spots. See page 228. **Tests 32, 28, 50.**

Opal. $SiO_2 + nH_2O$. H. = 5.5 to 6.5. G. = 2.1 to 2.2.

Translucent colorless or milk-white material sometimes with beautiful internal color reflections. More often without "opalescence" and with waxy luster, white to gray color, and tendency to break in shell-like curves. Also as dull pumice like, white or gray material near geysers and colorless masses like drops of melted glass.

Tests 20, 15, 32, 50.

Occurs in cavities and veins of igneous rocks as an alteration product. Also concentrated in limestone and clay and as deposit from hot water or steam.

Plagioclase $nNaAlSi_3O_8 + mCaAl_2Si_2O_8$. H. = 5 to 7. G. = 2.6 to 2.7.

Masses and (rarely) triclinic crystals which break smoothly in two directions at angles nearly but not exactly 90°. The surfaces resulting often show parallel grooves (striations). Sometimes opalescent. The principal varieties are:

Albite $NaAlSi_3O_8$ or Ab.

Usually pure white, often granular with curved cleavage surfaces. Associates: quartz, tourmaline, topaz, chlorite, beryl, rutile.

Anorthite $CaAl_2Si_2O_8$ or An.

Small highly modified glassy crystals or grayish-white larger crystals often covered with lava crust and enclosing chrysolite.

Oligoclase 2 to 6 Ab with 1 An.

Often glassy and colorless or grayish-white with very good cleavage and markedly good striations. Often with orthoclase, quartz, garnet and tourmaline.

Labradorite 1 Ab with 1 to 3 An. Gray masses which cleave in two directions at 86°, the resulting surfaces showing parallel grooves (striations). Usually shows beautiful play of colors.

Tests 37, 31, 50, sometimes 29.

In igneous rocks and schists, with quartz, orthoclase, mica, garnet, tourmaline.

Orthoclase $KAlSi_3O_8$. H. = 6 to 6.5. G. = 2.4 to 2.6.

Pinkish-white and yellowish-white masses and monoclinic crystals which cleave in two directions at exactly 90° to each other. The surfaces resulting are *not* grooved. Sometimes opalescent. **Tests 43, 31, 50.**

Very common in most igneous and many metamorphic rocks. Rare in contacts or sediments. With quartz, other feldspars, mica, epidote, etc.

Microcline $KAlSi_3O_8$. H. = 6 to 6.5. G. = 2.5 to 2.6.

Milk white crystals resembling those of orthoclase, but often striated on basal plane, and other crystals and cleavable masses only to be distinguished from orthoclase by tests with polarized light. **Tests 43, 31, 50.**

In many granites. With quartz, feldspars, topaz, phenacite.

Spodumene $LiAl(SiO_3)_2$. H. = 6.5 to 7. G. = 3.1 to 3.2.

Broad white or greenish-white plates or monoclinic crystals sometimes of enormous size. **Tests 36, 29, 38, 50.**

Occurs in granite pegmatites with quartz, feldspars, muscovite, lepidolite, tourmaline, beryl, cassiterite.

Sillimanite (Al_2SiO_5). H. = 6 to 7. G. = 3.2.

Long, almost fibrous orthorhombic crystals, and very tough fibrous or columnar masses and brownish-gray color. **Tests 32, 28, 50.**

In gneiss and crystalline schists, also a contact mineral in rocks high in alumina. Associates: andalusite, garnet, iolite, corundum.

THE FIFTY TESTS[1]

Although in general it may be assumed that the user of the scheme has access to works on blowpipe analysis, a brief description of each test is given for convenience.

It is recommended that before testing minerals a few preliminary tests be made, for instance in order 1, 5, 6, 10 13, 16, 20, 23, 27, 30, 40, 42, 47. This will greatly increase the accuracy of the subsequent testing.

By elements, etc., the numbers are as follows:

Element	Test
Aluminum	28
Antimony	9, 19
Arsenic	8, 21
Barium	41
Bismuth	17
Boron	44
Calcium	40
Carbonates	46
Chlorine	46
Chromium	6a
Cobalt	3, 12
Copper	5, 42
Fluorine	24
Iron	2, 12
Lead	16
Lithium	38
Magnesium	27
Manganese	6
Mercury	18, 23
Molybdenum	1
Nickel	4, 12
Nitrates	27
Phosphorus	45
Potassium	43
Silica	7, 15
Silver	13, 25
Sodium	37
Strontium	39
Sulphur	14, 22, 46
Titanium	7a
Tin	11
Zinc	10

Fusibility 29 to 36.
Solubility 46 to 52.

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[1] The *essential* pieces of apparatus for all the tests given are:

1. Either a gas blowpipe or some form of burner for gas or heavy oil and a plain blowpipe.
2. Platinum wire about .25 mm. diameter. Six inches will make four wires. A holder will be needed.
3. Platinum-pointed forceps.
4. Charcoal in convenient sizes and with smooth surfaces (say 4″ × 1″ × ⅜″).

For the other apparatus considerable latitude is possible and substitutes can be improvised for the regular stock article. The needed list would be watch glasses, bottles (1 oz.) for reagents, hammer, anvil, magnet.

For satisfactory work a good hand glass is very desirable.

Bead Tests[1] with Borax

Make a loop in platinum wire.

Bend it around a pencil point so that the end meets but does not cross the straight part.

Heat the loop, dip it into borax and fuse the portion that adheres to a clear bead. Add more borax until the bead is of full rounded shape.

Blow an oxidizing flame (O. F.).

If a lamp or Bunsen burner is used place the tip of the blowpipe almost touching the top of the burner, or the wick, and extending in one-third the breadth of the flame. With the gas blowpipe all that is necessary is to avoid an excess of gas.

Touch the warm bead to the substance, place it in the colorless mantle which surrounds the blue flame and treat until clear. Note the colors hot and cold.

Then blow a reducing flame (R. F.).

If a lamp or Bunsen burner is used, place the tip of the blowpipe one-eighth of an inch above and back of the middle of the flame, and turn the entire flame in the direction of the blast. With the gas blowpipe reduction is obtained by using a larger flame and inserting the bead within the yellow.

1. **Purity[2] of flames.**
Dip the hot bead into the MoO_3, dissolve the adhering material at the tip of the blue flame and make the bead alternately brown or black in the reducing flames and colorless in the oxidizing flame.

2. **Iron, Fe.** O. F. Yellow to red hot, colorless to yellow cold. R. F. Bottle green.

3. **Cobalt, Co.** Pure deep blue in either flame.

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[1] For safety substances should first be heated with a gentle flame on coal to drive off volatile compounds. Use a dull red heat and continue as long as fumes are given off.

[2] Manganese dioxide may be used instead. A borax bead is dipped while hot into the MnO_2 and heated in the oxidizing flame; if only a little MnO_2 is used the bead becomes violet-red when cold. It can be made colorless in the reducing flame by steady blowing. If more is used the bead will be nearly black when cold before reduction and amethystine after reduction.

4. **Nickel, Ni.** O. F. Violet hot, pale reddish-brown cold. R. F. Cloudy and finally clear and colorless.

5. **Copper, Cu.** O. F. Green hot, blue or greenish-blue cold. R. F. Greenish to colorless hot, opaque brownish-red when cold.

Bead Tests with Salt of Phosphorus

The bead is made on platinum wire as described for borax, except that in the making the bead should be held a little above the flame so that the ascending hot gases will help to retain the flux upon the wire.

The substance is added gradually to the warm bead and fused with it in the oxidizing flame.

The substances best determined by this test are:

6. **Manganese, Mn.** O. F. Amethystine hot, reddens on cooling. If a hot dilute bead is touched to a crystal of sodic nitrate a rose-colored froth is formed.

6a. **Chromium, Cr.** The hot bead is red, the cold bead emerald green in either flame.

7. **Silica, SiO_2.** Insoluble. The test made upon a small fragment will usually show a translucent mass of undissolved matter of the shape of the original fragment.

7a. **Titanium, Ti.** If finely powdered and dissolved with strong O.F. the resulting yellow-head may be turned bluish-violet in R.F.

Coatings and other Tests upon Charcoal either without Fluxes or mixed with Soda (Sodium Carbonate Dry)

A shallow cavity, sufficient to prevent the substance slipping, is bored at one end of the charcoal and a little of the substance is placed in it. The charcoal is held in the left hand, so that the surface is tipped at about 120° to the direction in which the flame is blown.

A gentle oxidizing flame is blown, the blue flame not touching the substance, but being just behind and in a line with it. If no sublimate forms the heat is increased, still keeping the flame oxidizing.

Any sublimate obtained is noted as to position, color, ease of driving with flame, etc.

After volatilization ceases with the oxidizing flame the reducing flame is used, the substance being kept covered for several minutes with the yellow flame.

The following substances are often determined by this test.

8. **Arsenic, As.** Very volatile white coat and strong garlic odor. Fumes invisible near assay after removal of flame. Soda assists the reaction.

9. **Antimony, Sb.** White volatile coat. The fumes are visible close to assay after removal of flame.

10. **Zinc, Zn.** Yellow non-volatile coat, white when cold. Best in R. F. with soda. If the coat is moistened with cobalt solution and strongly heated it becomes bright *yellowish*-green.

11. **Tin, Sn.** Strongly heated, forms a yellow coat, white when cold. Best in R. F. with soda. If the coat is moistened with cobalt solution and strongly heated it becomes *bluish*-green.

12. **Iron, Cobalt or Nickel.** Many compounds become magnetic in R. F. Soda assists the reaction.

13. **Silver, Ag.** Silver minerals heated on charcoal are decomposed and a malleable "button" results which if dissolved in a drop of nitric acid will yield a white curd-like precipitate on addition of a drop of hydrochloric acid.

14. **Sulphur, S.** Sulphides or sulphates mixed with soda and a little borax and thoroughly fused in the R. F., placed on bright silver, moistened, crushed and let stand, will stain the silver brown to black.

15. **Silica, SiO_2.** Mixed with soda, silica and silicates dissolve with effervescence to a bead which may be clear or opaque.

Coatings on Charcoal and Plaster[1] with Bismuth Flux[2]

The sublimates obtained on charcoal and plaster differ in position, and to some extent in color and supplement each other.

The method of using charcoal and plaster is the same.

The following elements are often determined by this test:

16. **Lead, Pb.** *On Plaster.*—Chrome yellow coat.
On Charcoal.—Greenish-yellow, equally voluminous coat.

17. **Bismuth, Bi.** *On Plaster.*—Chocolate-brown coat, with an underlying scarlet; with ammonia it becomes orange-yellow, and later cherry-red.
On Charcoal.—Bright red band with a fringe of yellow.

18. **Mercury, Hg.** *On Plaster.*—Scarlet coat with yellow, but if the substance is quickly heated the coat is dull yellow and black.
On Charcoal.—Faint yellow coat.

19. **Antimony, Sb.** *On Plaster.*—Orange coat stippled with peach-red.
On Charcoal.—Faint yellow coat.

E. TESTS IN CLOSED TUBES

A plain narrow glass tube about 3 in. by 3/16 in. and closed at one end is best.

Enough of the substance is slid down a narrow strip of paper, previously inserted in the tube, to fill it to the height of about one quarter inch; the paper is withdrawn and the inclined tube heated at the lower end gradually to a red heat.

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[1] Plaster tablets are prepared by making a paste of plaster of Paris and water, just thick enough to run, which is spread out upon a sheet of oiled glass and smoothed to a uniform thickness (1/8″ to 1/4″). While still soft, the paste is cut with a knife into uniform slabs, 4″ by 1 1/2″. It is then dried, after which the tablets are easily detached.

[2] Two parts of sulphur, one part of potassium iodide, one part of acid potassium sulphate.

Soda or other reagents are sometimes mixed with the substance. The following substances are often determined by this test:

20. **Water, H_2O.** Drops of moisture condense in the upper part of the tube. Sometimes the moisture is obtained at a low temperature, sometimes only at red heat.

21. **Arsenic and its Compounds.** May yield white oxide, yellow or red sulphide, or black mirror of metal. If the tube is broken and the mirror heated, a strong garlic odor will be noticed. Smaltite does not yield the red sublimate, arsenopyrite does, cobaltite is unaltered.

22. **Sulphur and Sulphides.** May yield sublimate of sulphur red when hot, yellow cold, or sublimate of undecomposed sulphide.

23. **Mercury, Hg.** Compounds mixed with dry soda and heated yield a mirror which may be collected into globules on a match.

24. **Fluorine, F.** Mixed with $KHSO_4$ and heated will corrode the glass in cloudy patches, which cannot be washed off.

25. **Cerargyrite, AgCl,** with $KHSO_4$ yields a globule yellow hot, white cold, becoming violet in sunlight, whereas embolite yields in same order dark red, deep yellow and green.

26. **Nitrates,** with $KHSO_4$ yield brown fumes with characteristic odor.

Tests with Cobalt Solution[1]

Certain substances moistened with cobalt solution and heated to a white heat become colored. The test is usually made upon charcoal.

The elements usually determined in this way are:

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[1] Cobalt nitrate dissolved in ten parts of water.

27. **Magnesium, Mg.** The substance moistened with the solution and *strongly* heated becomes a pale flesh or pink color. The arsenate, borate and phosphate become dark violet.

28. **Aluminum, Al,** and certain minerals such as colemanite, calamine and borax tested as for magnesium become fine blue when cold.

The test is also made upon sublimates supposed to be wholly or in part zinc oxide or tin oxide which become bright green and bluish green respectively.

Fusible silicates remain in doubt as many are colored blue by cobalt.

Fusibility

The relative ease of fusibility and the phenomena during fusion (or manner of fusion) are convenient tests in many instances.

The test will be most safely made as follows:

(*a*) If metallic or reducible, treat in a shallow hole on charcoal, using a fragment of the substance the size of a pin's head.

(*b*) If stony or vitreous, a small fragment with an edge as thin as paper *and long enough to project* say 1/8″ beyond the platinum forceps is selected and held in the hottest portion of the flame just beyond the tip of the blue. The flame should be directed especially on the point. The fragments should be examined with a magnifying glass *before* and *after* heating to determine whether the edges have or have not been rounded by the heat.

The degree or ease of fusibility may be given as:

29. Easily to a white enamel or colorless glass. Ex. Gypsum.

30. Easily to a colored enamel or glass. Ex. Garnet.

31. With difficulty or only on the edges. Ex. Orthoclase or with still more difficulty calamine.

32. Infusible. Ex. Quartz.

Certain phenomena on heating on charcoal, and not previously recorded, are sometimes available as tests.

33. Leaves a malleable metal.

33a. Leaves a magnetic residue.

34. Takes fire and burns with odor of SO_2.

35. Flies to pieces.

36. Swells considerably.

Flame Coloration

At the time of making the fusion test there may be weak or strong flame coloration, that is, the non-luminous mantle may become colored.

It is best in every case whether this was observed or not to make a test using the blowpipe flame and not the Bunsen burner alone as follows:

Powder the substance finely. Flatten the end of a clean platinum wire and dip it first in dilute hydrochloric acid, then in the powder. Arrange a black background such as a piece of charcoal.

Hold the wire first in the mantle flame near the wick and then at the hottest portion at the tip of the blue flame. Again dip in the acid and place in the flame.

The elements often determined by this test are:

37. **Sodium.** Bright yellow.

38. **Lithium.** Carmine red.

39. **Strontium.** Crimson.

40. **Calcium.** Red.

41. **Barium** or **Molybdenum.** Yellowish-green.

42. **Copper.** Azure blue.

43. **Potassium.** Violet (pale).

Certain elements are best determined by flames obtained from substances dipped in concentrated sulphuric acid.

44. **Boron.** Yellowish-green.

45. **Phosphorus.** Bluish-green.

Solubility

Acids, especially dilute (1:1) hydrochloric acid are used not only to determine composition but to determine the ease or degree of solubility.

The substance must be finely ground and small quantities added at a time to the cold dilute acid in a watch glass.

The acid is then slowly heated; all phenomena are noted.

A clear solution should be aimed for, acid being added if more is needed until everything has dissolved. If this cannot be done decant or filter the liquid.

The clear solution should now be slowly and partially evaporated till separation commences.

The more important results *with hydrochloric acid* may be stated.

46. Effervescence.

If the substance is non-metallic in luster the gas given off will usually be CO_2 showing that the substance was a carbonate. H_2S is easily recognized by its odor. Cl is yellowish and very offensive.

47. Gelatinous Residue. If a jelly forms after boiling away the larger part of the acid a silicate was present.

48. Easily soluble without effervescence.

49. Soluble partially or with difficulty.

50. Insoluble or nearly so.

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